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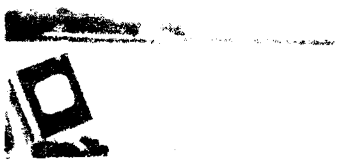

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EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: 1989 STUDIES

by

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In 1988, the US Army Engineer District, St. Louis (CELMS) initiated a program to analyze the effects of commercial navigation traffic on freshwater mussels (Mollusca:Unionidae), especially the endangered *Lampsilis higginsi* in the upper Mississippi River (UMR). In 1989 mussels were collected using qualitative and quantitative methods (0.25-sq-m total substrate samples) at dense and diverse beds in pool 24 (river mile (RM) 299), pool 14 (RM 505), and pool 10 (RM 635) of the UMR. Water velocity and suspended solids concentrations were measured immediately following vessel passage at beds in pools 10 and 14. An assessment of commercial navigation traffic effects will be based on a comparison of baseline data (1988-94) with information collected with less intensive sampling from 1994 to 2040.

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19. ABSTRACT (Continued).

The UMR mussel fauna was dominated by *Amblema plicata*, which comprised 27.7 percent of the qualitative collection, and was found in 87.1 percent of the samples. Total numbers of the endangered *L. higginsi* were variable; this species comprised slightly less than 0.5 percent of the bivalve assemblage and ranked 22nd out of 26 species collected using qualitative methods. Total bivalve density ranged from 31.2 ± 25.7 (± SD) individuals/ sq m to 184.8 ± 33.3 individuals/sq m at 24 sites on three mussel beds. With the exception of the bed in pool 24, nearshore densities were about twice as high as farshore densities. Differences in relative abundance for dominant species, species diversity (1.0 to 2.3), and evenness (0.38 to 0.81), with respect to distance from shore were minor compared to inter-pool differences. Pool 24 mussel assemblages, both nearshore and farshore, were characterized by very low abundance of old individuals and high abundance of relatively young mussels. At sites in pool 14, large and relatively old mussels were abundant and dominated the assemblage; demography of nearshore and farshore assemblages was virtually identical. Biotic parameters such as relative species abundance, total density, species diversity, and species richness were similar in 1988 and 1989.

Preliminary water velocity data following vessel passage at two mussel beds were obtained with Model 527 Marsh McBirney meters placed at nearshore (approximately 200 ft from shore) and farshore (approximately 400 ft from shore). Data indicated that a commercial vessel that passes within 500 to 800 ft of shore can cause a change of 1 to 2 fps for 50 to 200 sec immediately above the substrate-water interface near the center of the mussel bed.

PREFACE

In accord with the Endangered Species Act, Section 7, "Consultation," personnel from the US Army Engineer District, St. Louis (CELMS) and the US Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated that would assess the effects of existing and future increased commercial traffic levels on freshwater mussels including *Lampsilis higginsi*. Concern had been expressed by the USFWS and other agencies over projected increases in traffic resulting from completion of the Melvin Price Locks and Dam, Second Lock Project, at Alton, IL (formally known as Locks and Dam 26). In 1988, CELMS contracted with the US Army Engineer Waterways Experiment Station (WES) to initiate these studies. The purpose of the 1988 studies was to identify sample sites for future work and to initiate baseline data collection. This report describes results of the first full study year, which took place in 1989.

Divers for this study were Ron Fetting, Bill Wolf, Kenneth Schroeder, and Bob Sikkila, US Army Engineer District, St. Paul; and Larry Neill, Mitchell Marks, Steve McKinny, and Dennis Baxter from the Tennessee Valley Authority. Mr. Dan Ragland, CELMS, and Dr. Dan Hornbach, Macalester College, Minnesota, assisted in the field. Ms. Cheryl Tansky, University of Dayton, Ms. Sarah Wilkerson, Hinds Jr. College, and Dr. Ken Gordon, Jackson State University, Jackson, MS, assisted in the laboratory. Comments on an early draft of this report were provided by Messrs. Dan Ragland and Tom Keevin (CELMS), and by Ms. Gail Carmody and Mr. Gerry Bade, USFWS Rock Island Field Office. This report was edited by Ms. Janean Shirley of the WES Visual Production Center, Information Technology Laboratory.

During the conduct of these studies Dr. John Harrison was Chief, Environmental Laboratory (EL), WES, Dr. C. J. Kirby was Chief, Environmental Resources Division, EL, and Mr. E. Theriot was Chief of the Aquatic Habitat Group, EL, WES. Authors of this report were Drs. Andrew C. Miller and Barry S. Payne, WES.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN, and the Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.1745329	radians
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimetres
miles (US nautical)	1.852	kilometres

EFFECTS OF INCREASED COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS IN THE UPPER MISSISSIPPI RIVER: 1989 STUDIES

PART I: INTRODUCTION

Background

1. Operation of the second lock at the Melvin Price Locks and Dam (formerly the Locks and Dam 26 (Replacement) project) will increase the capacity for commercial navigation traffic in the upper Mississippi River (UMR). Increased commercial traffic could detrimentally affect freshwater mussels (Mollusca: Unionidae), including *Lampsilis higginsi*, listed as endangered by the US Fish and Wildlife Service (1989). In accordance with the Endangered Species Act, Section 7, "Consultation," personnel from the US Army Engineer District, St. Louis (CELMS) and the US Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated to assess the effects of projected traffic levels on freshwater mussels including *L. higginsi*. Other agencies that participated in the development of this program included the US Army Engineer Divisions, Lower Mississippi Valley and North Central; US Army Engineer Districts, St. Paul and Rock Island; and State conservation agencies and interested lay personnel.

2. Reconnaissance surveys to choose sample sites were conducted in 1988 and 1989. Detailed studies of mussel beds were initiated in 1989 and will continue through 1994 to obtain baseline data. After 1994, additional studies will be conducted until 2040 when commercial traffic is predicted to reach its maximum level. This report contains a summary of data collected during 1989.

3. In May, 1990, personnel from CELMS, USFWS, and the US Army Engineer Waterways Experiment Station (WES) met to discuss the research program on freshwater mussels. It was decided that physical studies would be conducted at each bed every other year when biological data were collected (a low-water period in summer or early fall).

Study Design

4. This research program was designed to obtain information on physical effects of commercial vessel passage (changes in water velocity and suspended solids near the substrate-water interface) at dense and diverse mussel beds in

the UMR. In addition, important biotic parameters (species richness, species diversity, density, growth rate, population structure of dominant mussel species, etc.) will be monitored at these beds every second year. An objective is to couple biological and physical studies so reliable predictions of the physical effects of vessel passage can be made. At each mussel bed physical and biological data are being collected at a farshore (experimental) and nearshore (reference) site. Experimental sites are located close to the navigation channel (affected by vessel passage), and reference sites are as far as possible from the channel (affected to a lesser extent by vessel passage).

5. Data are being collected to determine if commercial navigation traffic is negatively affecting *L. higginsi*. This is being accomplished by collecting information on all bivalve species. As appropriate, results will be applied to *L. higginsi*. This surrogate species concept is being used since it is extremely difficult to obtain information on density, recruitment, etc., for uncommon species such as *L. higginsi*. In addition, intensive collections of this species would be detrimental to its continued existence.

6. Results of the reconnaissance survey (1988), and 6 additional years (1989-94) of detailed study will provide baseline physical and biological data. Information obtained from studies to be conducted in 1995-2040 will be compared with results of baseline studies to determine if commercial traffic is having negative effects. The following six parameters, considered to be indicative of the health of a mussel bed, will be used to determine if commercial navigation traffic is negatively affecting freshwater mussels:

a. Decrease in density of five common-to-abundant species.

b. Presence of *L. higginsi*.

c. Live-to-recently-dead ratios for dominant species.

d. Loss of more than 25 percent of the mussel species.

e. Evidence of recent recruitment.

f. Significantly different growth rates or mortality.

7. Every mussel bed will be studied every other year until 1994; three nonconsecutive years of data will be obtained from each bed. Data will be collected during a period when traffic levels are not expected to increase. After 1994, biological and physical data will be collected at each bed once every 5 years. This will be done until traffic levels have increased by an average of one tow per day above 1990 levels in the pool where monitoring takes place. Studies will then resume at the original rate and continue until 2040, the economic life of the Melvin Price Locks and Dam Project. Results of

these studies will be reviewed annually to determine the need for altering sampling protocol. A preliminary schedule of studies to be conducted at each mussel bed appears in Table 1. A more complete description of these studies appears in Miller et al. (1990).

8. This experimental design will enable three types of comparisons:

a. Comparisons within mussel beds.

b. Comparisons among mussel beds.

c. Comparison between (or among) study years.

Purpose and Scope

9. The purpose of this research program (1989-94) is to obtain baseline data on physical (water velocity and suspended solids) and biological conditions (density, species richness, relative species abundance, population demography of dominant species, etc.) at five mussel beds between river miles (RMs) 299 and 635 in the UMR. The purpose of the 1989 studies was to collect biological and physical data at mussel beds in pool 24 (RM 299), pool 14 (RM 505), and pool 10 (RM 635). This information will be used to determine if, and to what extent, commercial navigation traffic affects freshwater mussels and *L. higginsi* in the UMR. Sites in the UMR that were surveyed for bivalves are depicted in Appendix A. Bivalves collected using qualitative techniques are listed in Appendix B, whereas Appendix C contains bivalves collected using quantitative techniques. Length-frequency histograms can be found in Appendix D, and water velocity data in Appendix E.

PART II: STUDY AREA AND METHODS

Study Area

10. The UMR was once a free-flowing, braided, pool-riffle habitat with side channels, sloughs, and abandoned channels. Development of the 9-ft* navigation channel, which included placement of locks, dams, dikes, wing dams, and levees, converted it to a series of run-of-the-river reservoirs, characterized by relatively slow-moving water and extensive adjacent lentic habitats. Typically the upper reaches of pools in the UMR have relatively high water velocity and riverine conditions whereas the lower reaches are more lake-like with deep, low-velocity water and fine-grained sediments. At study sites, substrate in pools 26-24 consisted mainly of coarse gravel, cobble, and slab rock. The channel was fairly narrow, deep, with comparatively few side channels, islands, or backwaters. Study sites in the middle reach of the UMR (pools 22-17) were characterized by fine-grained sediments, numerous islands, sloughs, and backwaters. Survey sites upriver of pool 17 had extensive islands, backwaters, sloughs, and aquatic macrophyte beds. Substrate consisted almost entirely of fine-grained sand and silt (Miller et al. 1990).

Study Sites

11. In 1988 preliminary data on physical and biological conditions were collected at mussel beds in pools 26, 25, 24, 19, 18, 17, 14, 10, and 7. In 1989 additional surveys were conducted in pools 12 and 13 (Appendix A). In these reconnaissance surveys, a combination of qualitative and quantitative techniques were employed to determine if the bed was suitable for detailed study. Based on information collected from these surveys, the following mussel beds were identified for detailed study:

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Pool	RM
24	299.6
17	450.0
14	505.5
12	571.4
10	635.0

Pool 24

12. This mussel bed is on the right descending bank approximately 1.5 miles downriver of Lock and Dam 22 (Figure 1). A series of wing dams on the left descending bank (LDB) direct water toward the mussel bed. Commercial traffic must move along the right descending bank (RDB) when approaching or exiting Lock and Dam 22. The substrate consists of slab rock, coarse gravel, and sand. Ten quantitative and 18 qualitative samples were obtained during the preliminary survey in 1988, and a full complement of quantitative (60) and qualitative (42) samples were collected in 1989. Although *L. higginsi* has never been found in pool 24, this mussel bed contains a dense and diverse assemblage of mussels. This site was included in the monitoring program because it was deemed necessary to conduct studies in the lower UMR.

Pool 17

13. A mussel bed was identified in pool 17 in 1988 during the reconnaissance survey. A single *L. higginsi* was found in a qualitative sample of 567 individuals (Miller et al. 1990). At that time, 20 quantitative samples were collected at RM 450.4; however, no *L. higginsi* were found. Because of interest expressed by USFWS personnel in having a monitoring site in the middle river (pools 17-19), this mussel bed was chosen for detailed study. Additional reconnaissance will be done in 1990 at this bed; if still deemed appropriate, detailed studies will then begin at this location (Table 1).

Pool 14

14. An extensive mussel bed exists in the lower portion of pool 14 on the LDB (Figure 2). This bed supports a dense and diverse assemblage of mussels including *L. higginsi* which was obtained in qualitative and quantitative samples collected in 1988. Detailed biological and physical studies began at this location in 1989 and will continue through 1994.

Pool 12

15. The results of preliminary sampling in 1989 indicated that a mussel bed at RM 571 would be suitable for detailed study (Appendix A). The bed is

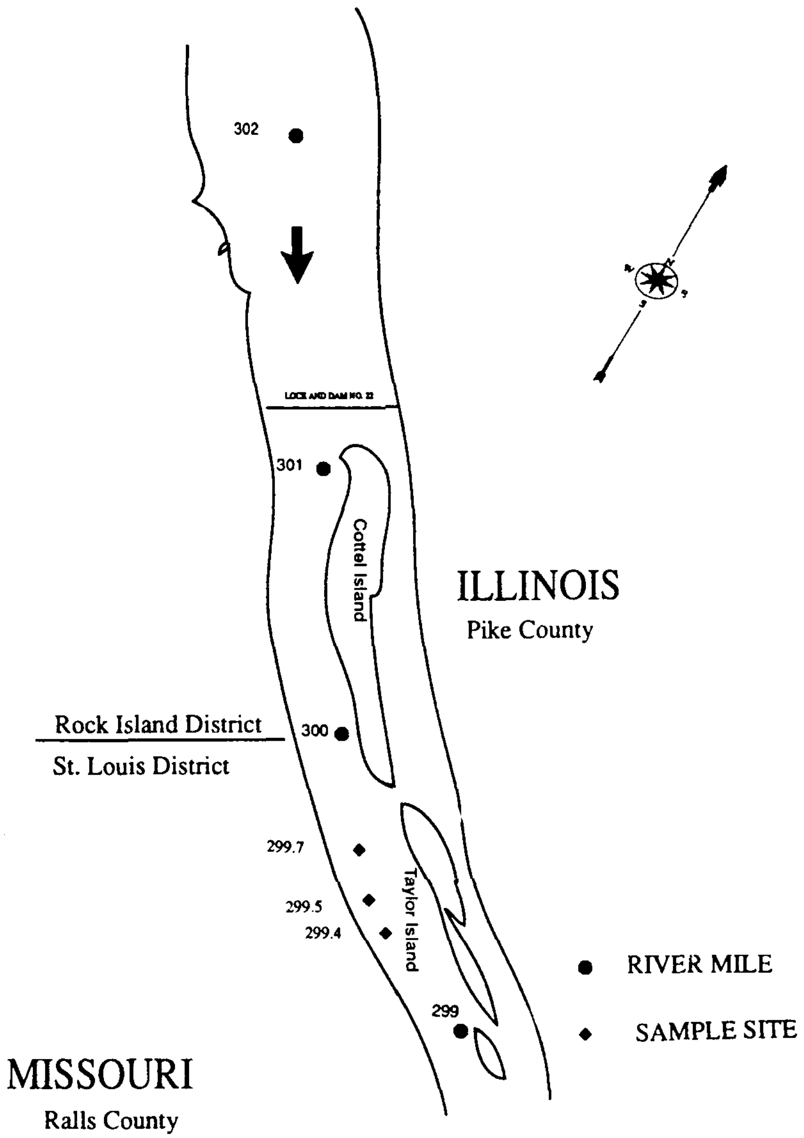


Figure 1. Sampling sites at the mussel bed located in pool 24, RM 299

on the RDB immediately downriver of a sharp left turn. Commercial tows moving up or downriver approach the RDB (and the mussel bed) as they enter or exit the turn. The bed is long and narrow, densities appeared to be moderate to high, and a single *L. higginsi* was found in a qualitative collection of 158 individuals.

16. At a mussel bed on the LDB near Dubuque, IA (RM 580.1) two *L. higginsi* were found in a qualitative sample that included 193 individuals. However, this site was close to the lock and dam, potentially affected by a recent bridge construction, and relatively removed from the navigation

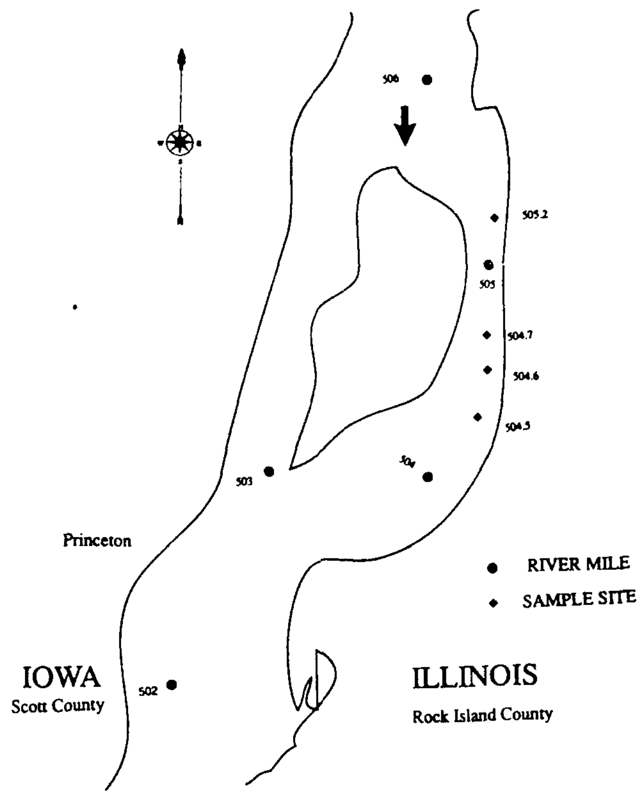


Figure 2. Sampling sites at the mussel bed located in pool 14, RM 505

channel. If additional study during 1990 indicates that the previously discussed site at RM 571 is unsuitable, the bed near Dubuque could be chosen for detailed study.

<u>Pool 10</u>

17. Detailed biological and physical studies were conducted in the main channel of the UMR near Prairie du Chien, WI in 1989 (Figure 3). Dense and diverse mussel populations exist on both sides of the river although the beds are narrow. In addition, studies have been conducted in the nearby east channel by WES personnel since 1984. Samples were collected at a barge turning basin in the north end of the east channel and a reference site about 1.0 km downriver. The turning basin is affected by wave wash, elevated turbidity, and benthic scour by tows. The reference site is relatively unaffected by commercial tows. For this program, all studies will be concentrated in the main channel of the river (Table 1).

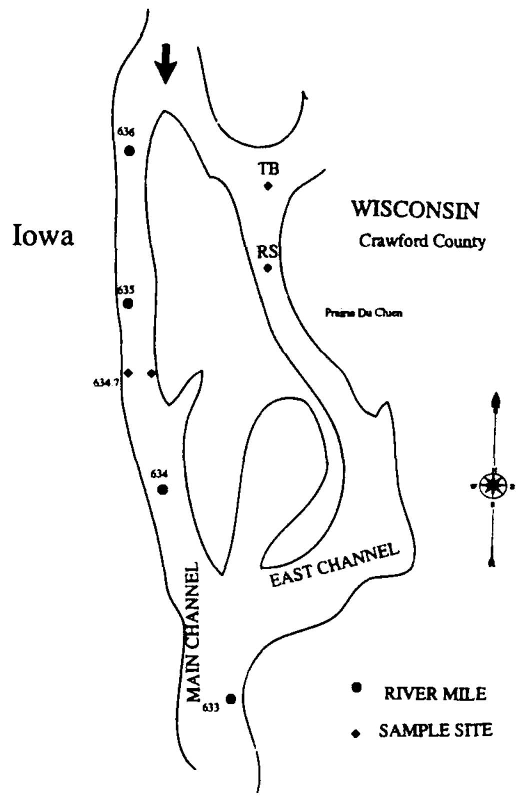


Figure 3. Sampling sites at the mussel bed located in pool 10, RM 635

Methods

Preliminary reconnaissance

18. The majority of the reconnaissance studies were conducted in 1988; however, selected beds in pools 12 and 13 were examined for suitable sites during 1989. Information on mussel beds was obtained from navigation maps (Peterson 1984) and discussion with knowledgeable individuals. Before intensive sampling was initiated, a diver made a preliminary survey of the mussel bed. He obtained information on substrate type, water velocity, and presence of mussels. A Fathometer was used to measure water depth, and distance to shore was determined with an optical range finder. If it appeared that detailed studies could be conducted at the bed, then qualitative sampling was initiated.

Qualitative collections

19. Qualitative collections were made at suitable sites by one or more divers equipped with scuba or surface air supply (Table 2). Divers were

instructed to search for and retain all live mussels until a sample of approximately 20 individuals was obtained. Usually at least nine samples of about 20 individuals (held in nylon bags) were obtained at each site. Collecting was done mainly by feel since water visibility was poor. Mussels were brought to the boat and identified. Selected individuals were shucked and retained for voucher. Additional specimens were preserved in 10-percent buffered Formalin and returned to the laboratory for analysis of physical condition (ratios of shell length to tissue dry mass, etc.). Unneeded specimens were returned to the river.

Quantitative sampling

20. At each mussel bed, nearshore and farshore sites were located with an optical range finder. At each site ten 0.25-m^2 quadrat samples were obtained at each of three subsites separated by 5 to 10 m. At each subsite, quadrats were placed approximately 1 m apart and arranged in a 2 by 5 matrix. A diver removed all sand, gravel, shells, and live molluscs within the quadrat. It usually took 5 to 10 min to clear the quadrat to a depth of 10 to 15 cm. All material was sent to the surface in a 20-ℓ bucket, taken to shore, and sieved through a nested screen series (finest screen with apertures of 6.4 mm) and picked for live organisms. All bivalves were identified, weighed to the nearest 0.01 g on an electric top-loading balance, and total shell length was measured to the nearest 0.1 mm. All *L. higginsi* were returned to the river unharmed. Some of the bivalves were measured in the evening, then returned to the river the next day. Bivalves that could not be processed within 24 hr were preserved in 10-percent buffered Formalin and taken to WES for analysis.

Physical condition analysis

21. Total blotted wet weight was determined on preserved specimens in the laboratory using an electronic top-loading Ohaus balance. Total shell length was measured with vernier calipers. Mussels were then opened by cutting the adductor muscles, and wet tissues and shells were placed separately in a drying oven at 65° C. After 24 hr, shells and tissues were removed and reweighed. Condition indices consisted of ratios between shell length and tissue dry mass or shell dry mass.

Water velocity readings

22. Water velocity was measured 23 cm above the substrate-water interface using the Marsh McBirney Model 527 current meter. The sensor for this instrument measures velocity in two directions (an X and Y component that are

at right angles to each other) and is equipped with a compass. The compass, which is read from the meter, assists in positioning the sensor and can be used to calculate direction of flow. The meter sensor was mounted in a concrete block, positioned, and secured by divers (Figure 4). Each meter was equipped with a 1,000-ft spool of cable. Water velocity in two directions and a compass reading were obtained at 1-sec intervals and stored on a model CR10 data logger (Campbell Scientific, Inc., Logan, UT). Data were downloaded to a Toshiba lap-top personal computer for later analysis and plotting.

23. During 1989, the effects of commercial vessel passage on water velocity were studied at two dense and diverse mussel beds. In Julv, data were collected along the LDB at RM 505 (pool 14). In September, data were collected along the LDB and the RDB in the main channel of the UMR at RM 635 (pool 10). The river flows south (i.e., 180 deg from due north) at both locations (See Figures 2 and 3). Two sensors were deployed, one at a nearshore station (usually within 100 to 300 ft from shore) and one at a farshore station (usually 200 to 500 ft from shore). Each probe was positioned to obtain velocity readings parallel to (pointing upriver) and at right angles (pointing into the channel) to the direction of flow. When the probes were on the LDB the parallel component was labeled as X and the perpendicular as Y. When the probes were on the right descending bank the Y component was parallel to flow and the X component was at right angles to flow.

24. The sensors were placed in position at the beginning of the day and retrieved every evening. When a commercial vessel was spotted, the meters and data logger were turned on and continuous data on water velocity and compass readings were obtained until the vessel passed. At locations where sensors were placed, tow speed was unaffected by the presence of bridges, marinas, or other impediments to navigation. Data on distance to shore, type of vessel, direction, etc., were noted. Table E1 (Appendix E) includes pertinent information on 16 separate tests or events. The range of conditions studied in 1989 include up- and down-bound events with lineboats or workboats pushing loaded or unloaded barges. In addition, data on ambient conditions (no vessels present) were obtained at each location. The data discussed in this report represent less than half the information that was collected in the summer of 1989. When several events were similar, a representative was chosen for plotting and discussion.

25. All water velocity data were converted to ASCII files and magnitude of flow was calculated from individual velocity components by the formula:

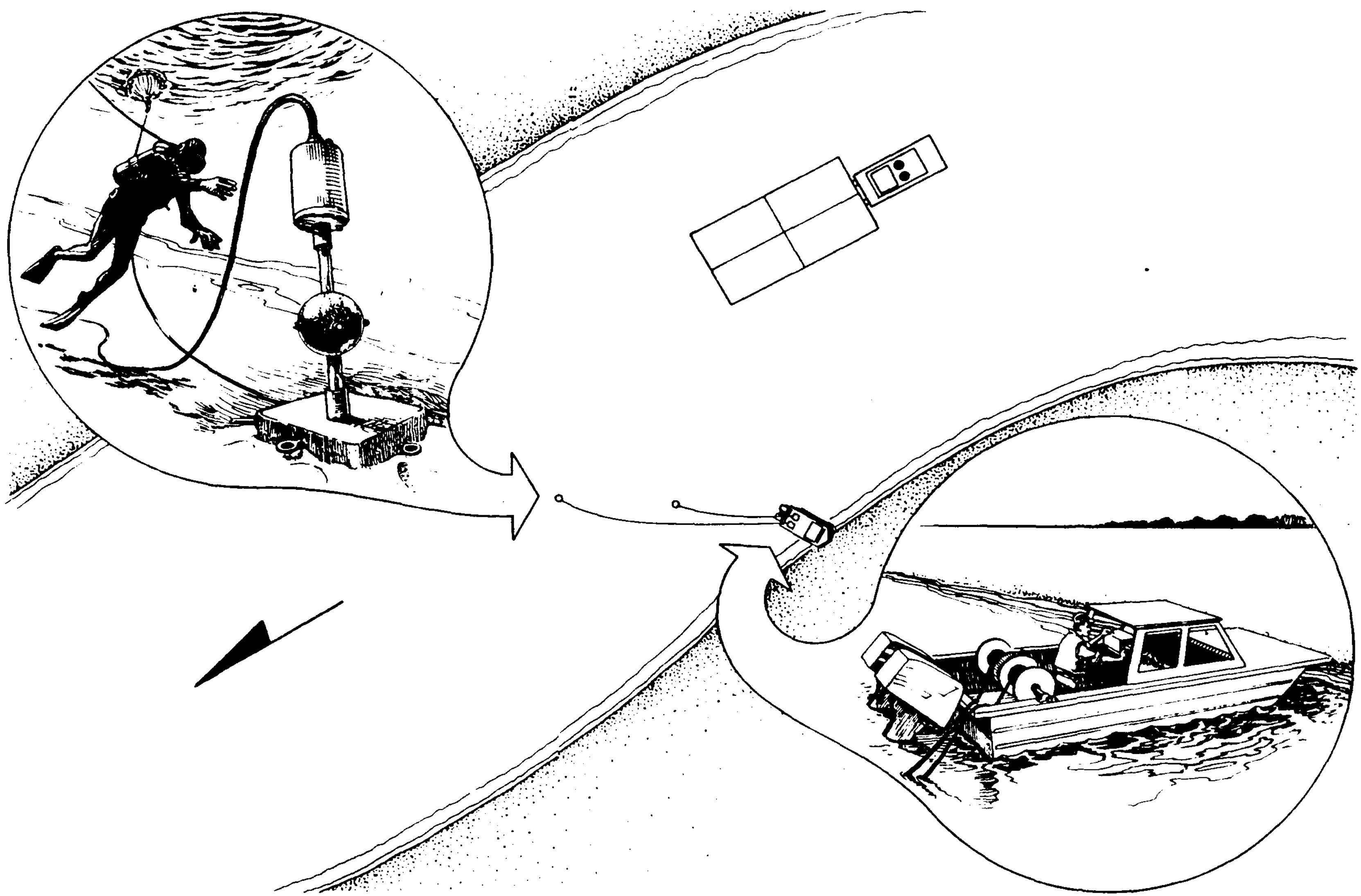


Figure 4. Placing the sensors for the Model 527 velocity meters

$$\text{Magnitude} = (X^2 + Y^2)^{0.5} \tag{1}$$

The resolved angle of water flow was determined by the formulae:

$$\theta = \mathrm{TAN}^{-1}\ (X/Y) \quad \text{if } Y \geq 0, \text{ or} \tag{2}$$

$$\theta = \mathrm{TAN}^{-1}\ (X/Y) + 180°, \text{ if } Y < 0 \tag{3}$$

Minimum and maximum values for the mean and standard deviation were calculated for a 200-sec increment (starting 50 sec prior to vessel passage).

Suspended solids

26. Water for suspended solids was collected 10 cm above the substrate-water interface at the same locations where velocity was measured. Water was brought to the surface through a 25-ft length of rubber hose secured to a concrete block (Figure 5). Suction was provided by a 12-volt Water Puppy Pump. The pump ran continuously and a 500-ml bottle was filled every 10 seconds. Samples were preserved with a few milliliters of 10-percent Formalin. In the laboratory, an aliquot of water was filtered through preweighed 0.45 μ filters, dried at 105° C, and weighed.

Data analysis

27. All bivalve data (lengths, weights, etc.) were entered on a spreadsheet and stored in ASCII files. Summary statistics were obtained using functions in the spreadsheets or with programs written in BASIC or SAS. All computations were accomplished with an IBM or compatible personal computer. All biological and physical data were plotted directly from ASCII files using a Macintosh SE computer and laser printer.

Figure 5. Placement of pumps and hoses to obtain water samples near the substrate-water interface

PART III: THE BIVALVE COMMUNITY

Community Characteristics

28. A total of 4,472 bivalves were collected in 286 separate qualitative collections at sites in pools 24, 14, 13, 12, and 10 in July and September, 1989 (Table 3). The number of samples collected and locations investigated in each pool were: pool 24 (4 locations and 42 samples), pool 14 (5 locations and 59 samples), pool 13 (7 locations and 78 samples), pool 12 (8 locations and 93 samples), and pool 10 (2 locations and 14 samples) (Appendix B, Tables B2 and B3). *Amblema plicata* dominated, comprised 27.7 percent of the collection, and was found in 87.1 percent of the samples. Plotting the relative abundance of each species versus its rank for all mussels (Figure 6) illustrates that the collection spans four orders of magnitude. *Amblema plicata* was more than twice as common as the next most abundant species. Nine species were common and comprised 4.6 to 11.6 percent of all mussels taken. Sixteen species made up 2.3 percent or less of the collection.

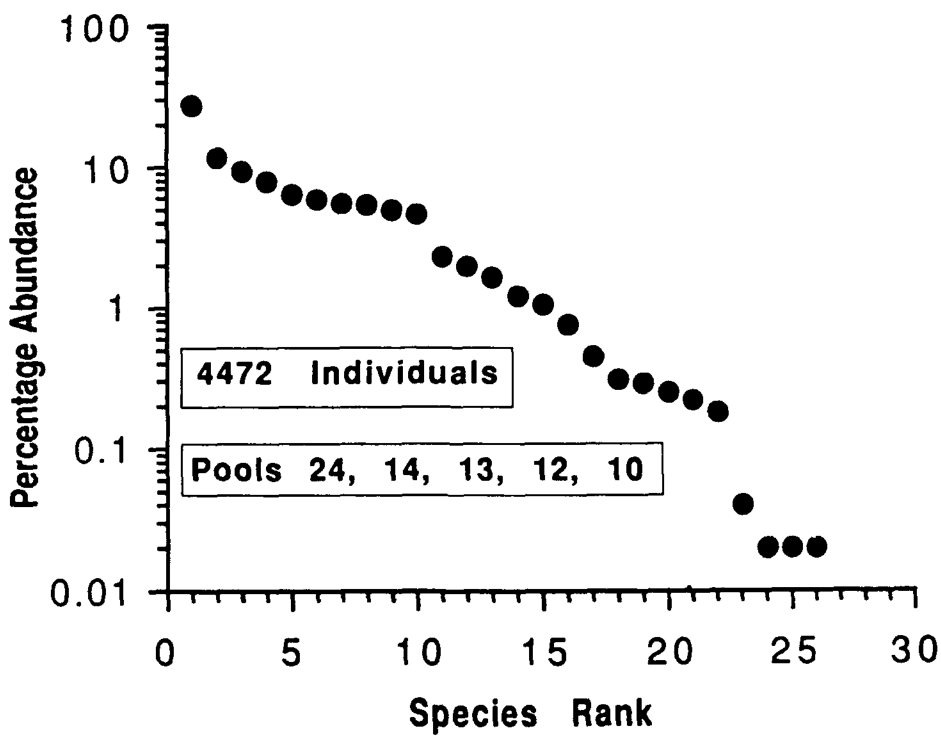


Figure 6. Percentage abundance versus species rank for all mussels collected using qualitative methods in five pools in the UMR, 1989

29. Eight *L. higginsi*, listed as endangered by the USFWS (1987), were obtained in eight separate samples collected in pools 14 and 12. This species, which ranked 22nd, was considered fairly common. Four species were less common than *L. higginsi*.

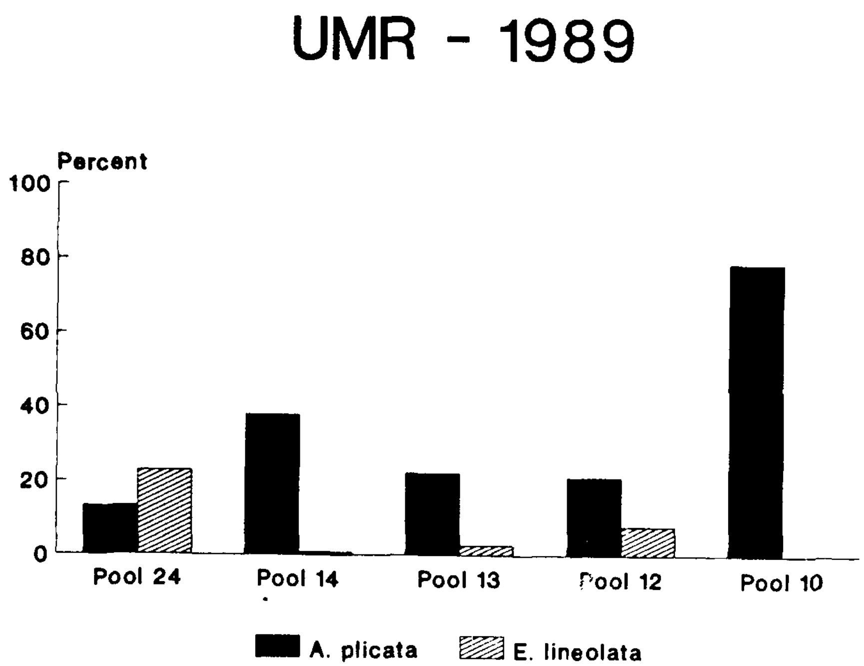
30. There was considerable variation in relative abundance of dominant species with respect to river mile. *Amblema plicata* was more common in pool 10 than it was at sites in pools 24, 14, 13, or 12. *Ellipsaria lineolata* was fairly common in pool 24 and was not found in pool 10 (Figure 7A). However, within-bed variation can mask between-pool trends. In the bed at RM 299 (pool 24) the percentages of *A. plicata* and *E. lineolata* ranged from 7.4 to 20.6 percent and 14.6 to 30.8 percent, respectively, depending on location and distance to shore (Figure 7b). Throughout the bed at RM 505 (pool 14) the relative percentages of *A. plicata* and *O. reflexa* varied by approximately 13 and 30 percent, respectively (Figure 7c, and Table B2 in Appendix B).

31. The relation between species rank and percentage abundance was similar at each location regardless of distance to shore (Figures 8a-8d). When data are compared across pools, the strong dominance of *A. plicata* in pool 10 (RM 635) is apparent. Although the main channel and east channel at this location differ with respect to current velocity and depth, the character of the bivalve assemblage is similar and differs from that in the lower pools. The extreme dominance of *A. plicata* in the upper pools has a strong effect on dominance diversity curves at RM 635.

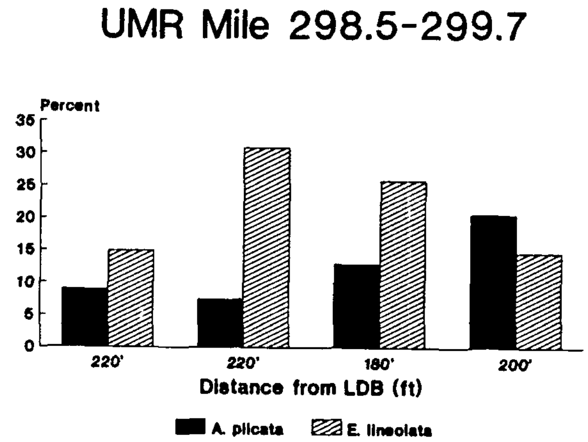
Bivalve Density

32. Total density at the nearshore site at RM 299.6 was approximately three times greater than at the farshore site (36.9 versus 115.6, which was significantly different, $F = 40.85$, $p = 0.0001$, see Table 4). Individual means for subsites at the nearshore site were not significantly different ($F = 0.88$, $p = 0.4248$). In contrast, there was significant intra-site variability at the farshore site ($F = 7.04$, $p = 0.0035$). Even at specific locations within a mussel bed there can be considerable variation within a subsite. An understanding of this variation is necessary to accurately evaluate environmental effects of commercial navigation traffic.

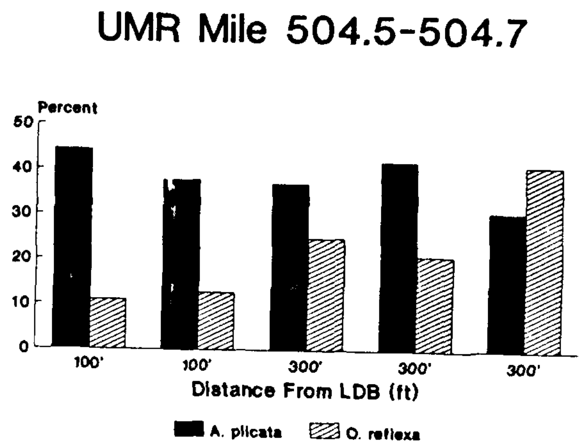
33. At the bed in pool 14, total densities were greater at the farshore than the nearshore site (69.3 versus 59.1 individuals per sq m, Table 5). Density data at distances of 100, 160, 300, and 400 ft from the LDB (Figure 9)



a. Qualitative sampling at 5 pools in the UMR

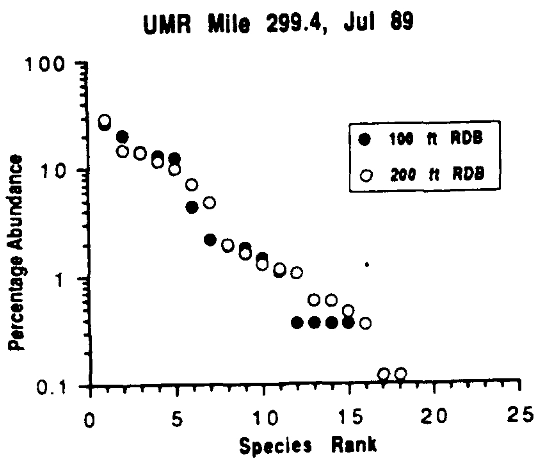


b. Qualitative sampling at pool 24

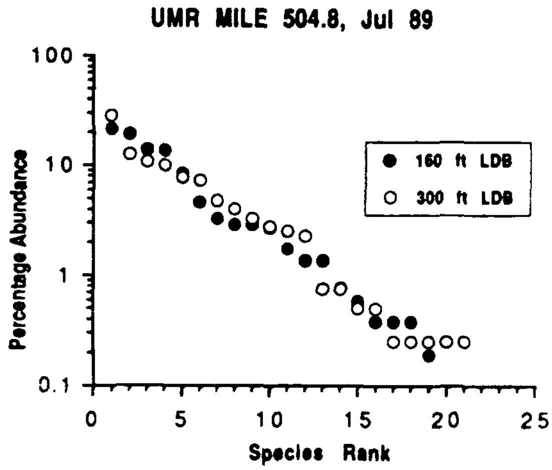


c. Qualitative sampling at pool 14

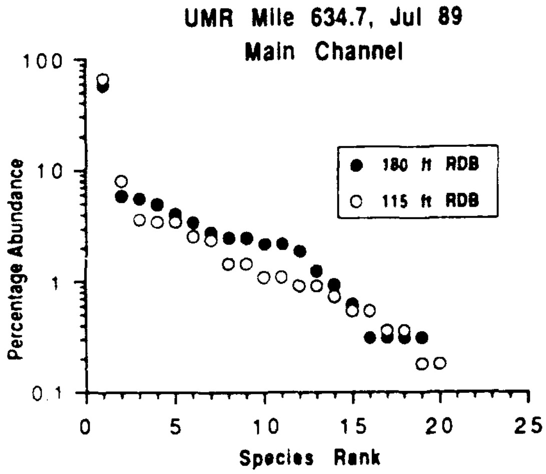
Figure 7. Relative species abundance, 1989



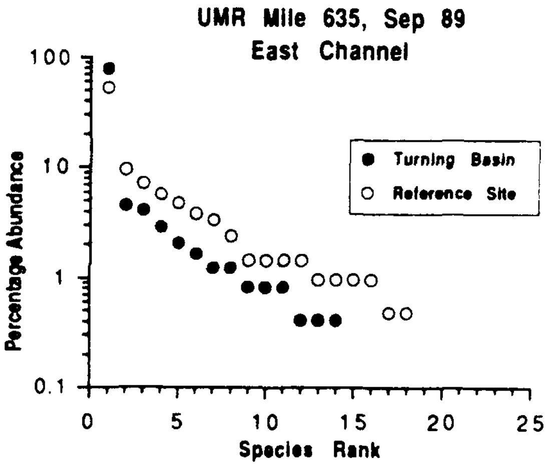
a. Near RM 299



b. Near RM 505



c. Near RM 635 main channel



d. Near RM 635 east channel

Figure 8. Percentage abundance versus species rank for freshwater mussels collected using quantitative techniques near RM 299

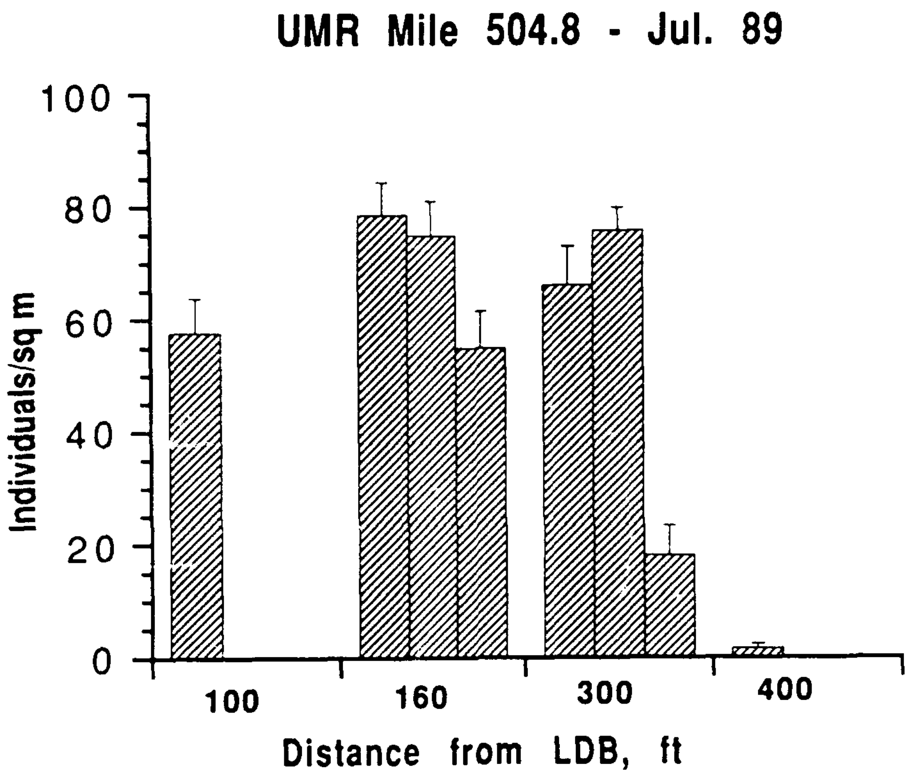


Figure 9. Total density of freshwater mussels at selected distances from the LDB, near RM 505, 1989

indicate that this bed did not extend more than 400 ft from the shore. Within-site variability at nearshore and farshore sites (160 and 300 ft from the LDB) was significantly different at the 0.05 level (p = 0.0252 and 0.0001, respectively).

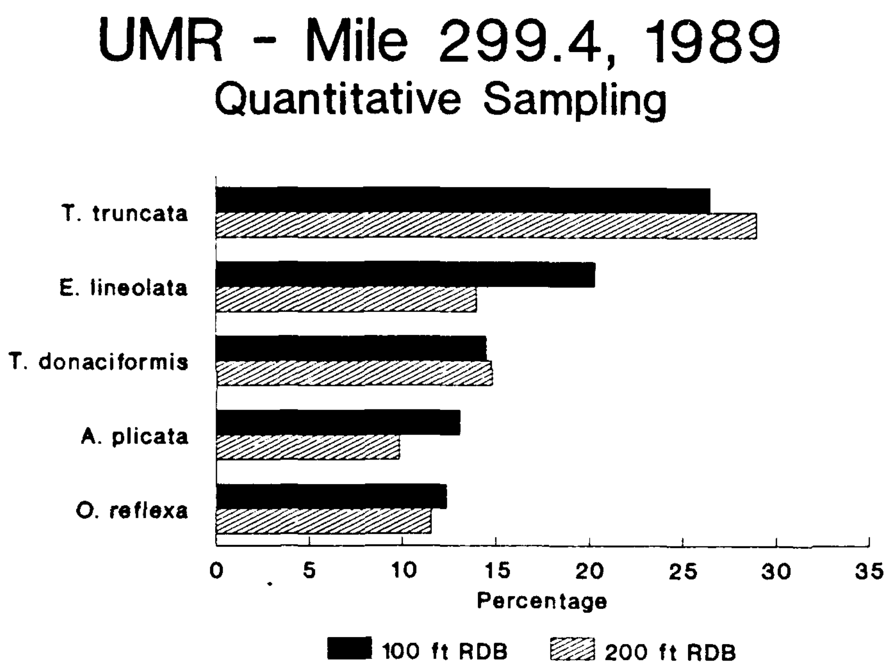
34. Mussel densities ranged from 32.0 to 112 individuals per square meter at six locations near RM 635 (Table 6). Densities were about 50 percent less in the turning basin in the east channel (32.0 and 65.2 individuals per sq meter) than they were in the main channel on the Iowa side of the river (112.4 and 108.0 individuals per square meter). Intrasite variation at the nearshore site along the main channel on the Iowa side was significant at the 0.05 level (p = 0.0165). However, variability among subsites at the farshore site (p = 0.7505) was not significant. Total density differences between nearshore and farshore sites on the Iowa side were significantly different (110.2 versus 64.6 individuals per sq meter, F = 30.27, p = 0.0001).

Inter-Pool Differences in Community Characteristics

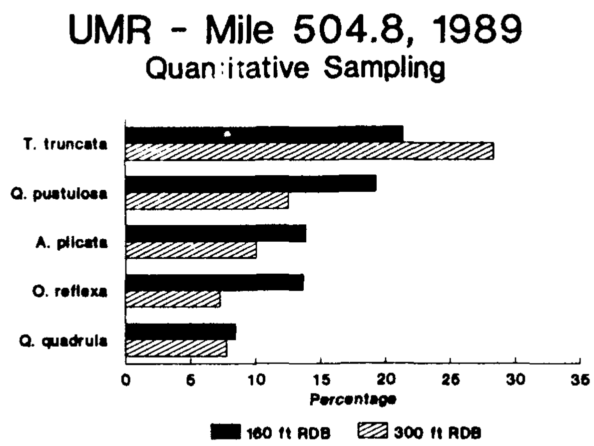
35. Results of the quantitative sampling in pools 24, 14, and 10 appear in Appendix C. Included are relative species abundance and frequency of occurrence for nearshore and farshore sites, and summary information (species richness, diversity, and evenness). Quantitative sampling is required to provide estimates of these parameters. Differences in relative species abundance for the six dominant species at each bed with respect to distance from shore are minor compared to inter-pool differences (Figure 10). These figures illustrate the extreme abundance of *A. plicata* and lack of *E. lineolata* in pool 10. Although total bivalve density is affected by distance to shore and water depth, relative abundance of most species was similar at near and far-shore sites. There were differences in species diversity (H'), evenness, and evidence of recent recruitment (defined as mussels less than 30 mm total shell length) at beds in pools 24, 14, and 10 (Figure 11). Differences with respect to distance to shore were minor when compared to differences between beds. The low diversity and evenness at the site in pool 10 (RM 635) was the result of dominance of a single species, *A. plicata*.

The Ability to Find Rare Species

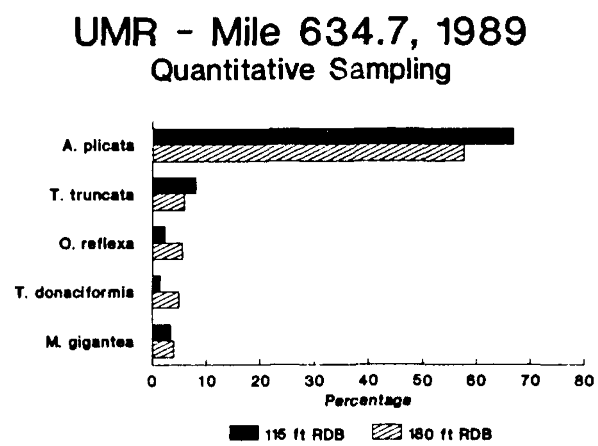
36. A major objective of this research program is to document the effort required to collect the endangered *L. higginsi* using qualitative and quantitative techniques. The ability to find this species will be evaluated each year to determine if commercial traffic is having negative effects. Finding uncommon species depends on sampling effort; i.e., uncommon organisms should not be considered absent unless sufficient numbers of samples have been collected (see Figures 12a-12b). An equal number of samples (10 at each of 3 subsites) were collected at nearshore and farshore sites at RM 299. However, more than three times as many individuals were obtained 200 ft from shore as compared with 100 ft from the shore. After collecting 276 individuals 100 ft from shore, 15 species were identified; whereas after collecting 867 individuals 200 ft from shore, 18 species were found (Table C1). At RM 505, 520 individuals and 19 species were found 160 ft from the LDB; 399 individuals and 21 species were found 300 ft from the LDB (Table C5). In pool 14, four species were collected at the farshore site but were not found



a. Pool 24

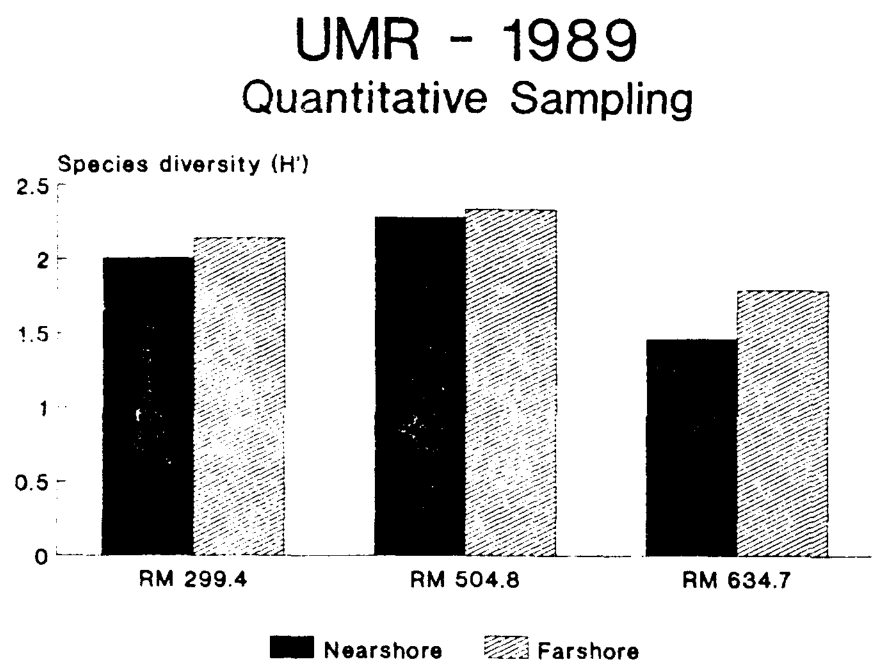


b. Pool 14

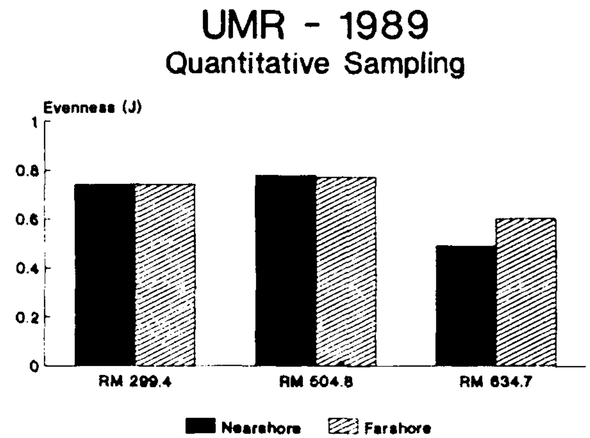


c. Pool 10

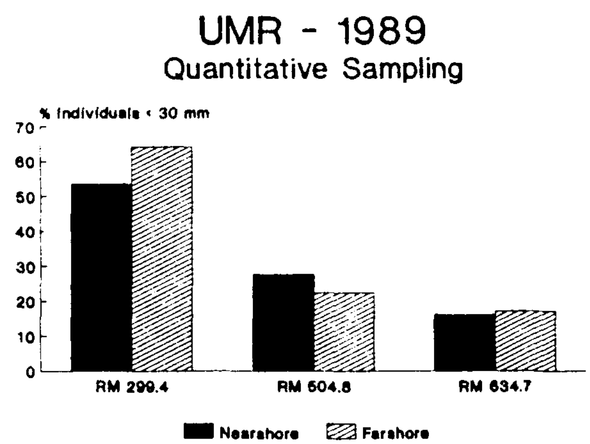
Figure 10. Relative species abundance of dominant freshwater mussels



a. Species diversity

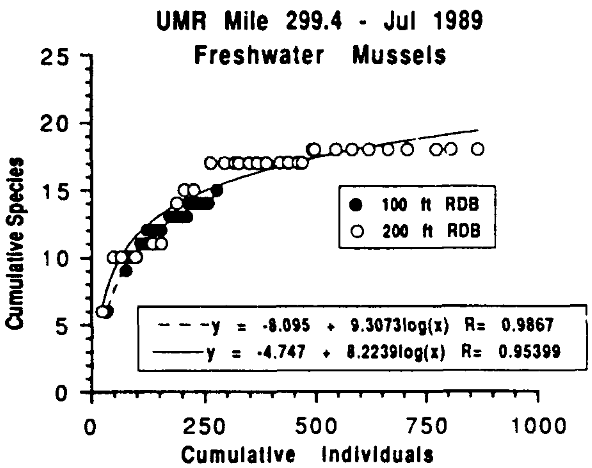


b. Evenness

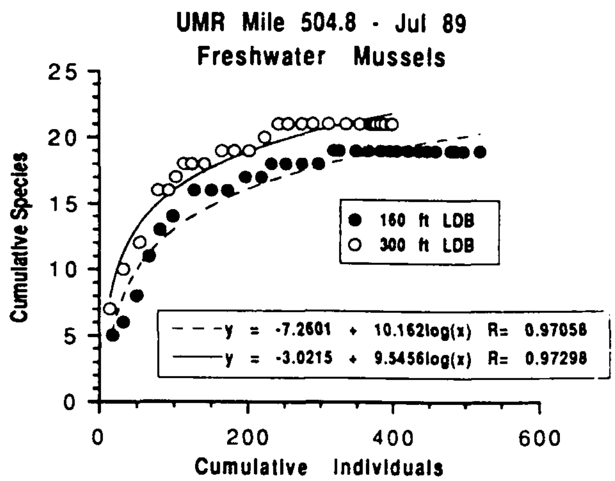


c. Evidence of recent recruitment

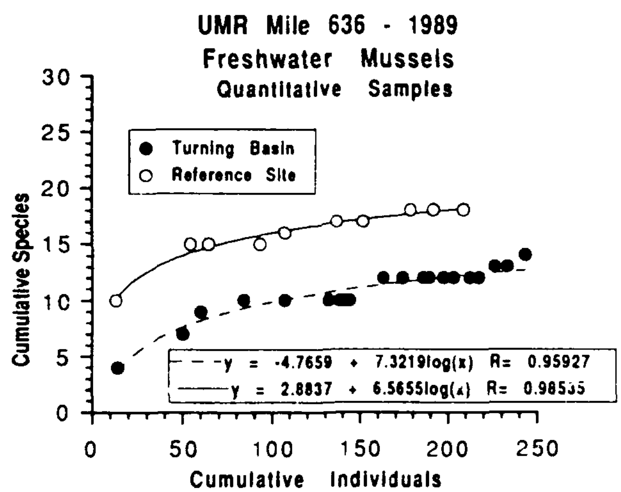
Figure 11. Differences in community characteristics at RM 299, RM 504, and RM 635



a. Pool 24



b. Pool 14



c. Pool 10

Figure 12. Cumulative species versus cumulative individuals based on quantitative sampling

at the nearshore site (*L. higginsi*, *E. dilatata*, *L. complanata*, and *P. laevissima*). Intensive sampling is required to obtain all species present at each site. Although 20 samples were collected in the turning basin of the east channel (pool 10) compared with 10 samples at the reference site, the higher densities at the latter site made it more likely to obtain uncommon species (Figure 12c).

Between-Year Comparisons

37. The relative percentage of *L. higginsi* taken in 1988 and 1989 was variable (Table 7). Sampling of approximately equal intensity must be conducted at all sites to assess the abundance of this species. However, the ability to find a species such as *L. higginsi* is also dependent on chance. At RM 505 (pool 14), more than 750 individuals were collected and 21 and 20 species were found in 1989 and 1988, respectively (Figure 13). *Lampsilis higginsi* was found both years using qualitative and quantitative methods (Table 7). Data on the presence of *L. higginsi* will be used to determine whether commercial navigation traffic has negative effects.

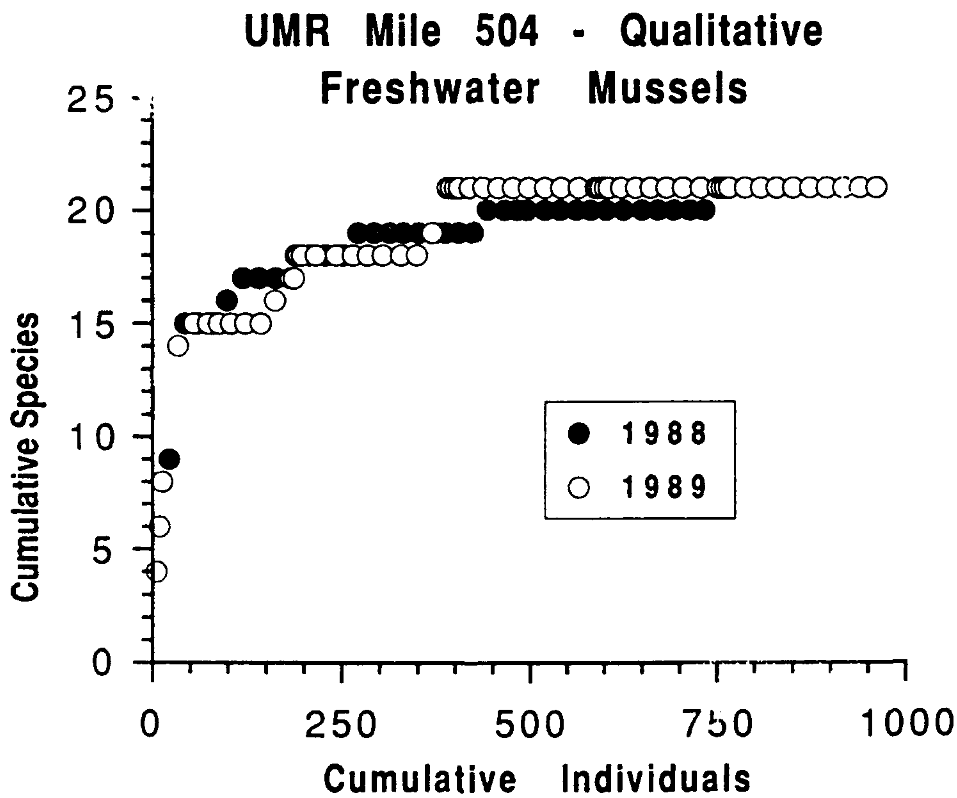
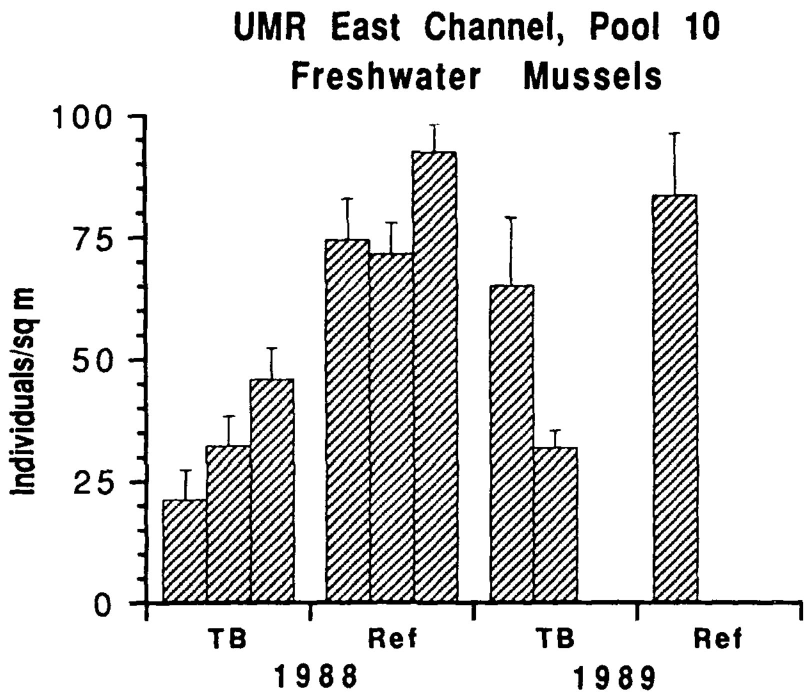
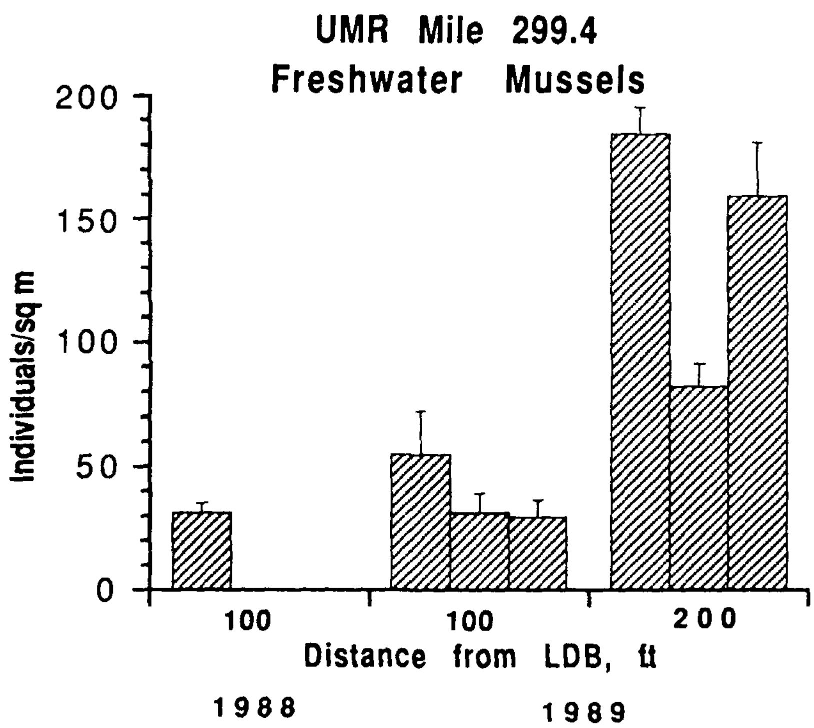


Figure 13. Cumulative species versus cumulative individuals based on qualitative sampling near RM 505 in 1988 and 1989

38. A major objective of this research program is to analyze inter-year density differences. Inspection of Figures 14a and 14b indicates that there have been no substantial density differences between 1988 and 1989 at beds in pools 24 and 10. Differences in the percentage of dominant species at beds in pool 14 (Figures 15a and 15b) and pool 24 (Figure 15c) between years was negligible.

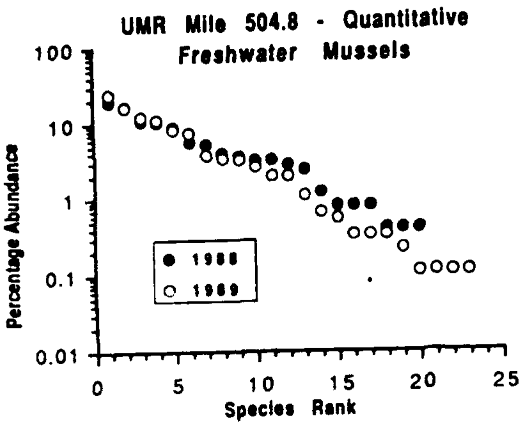


a. Near RM 635

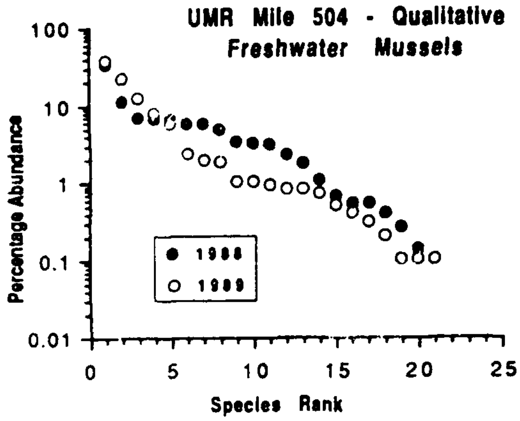


b. Near RM 299

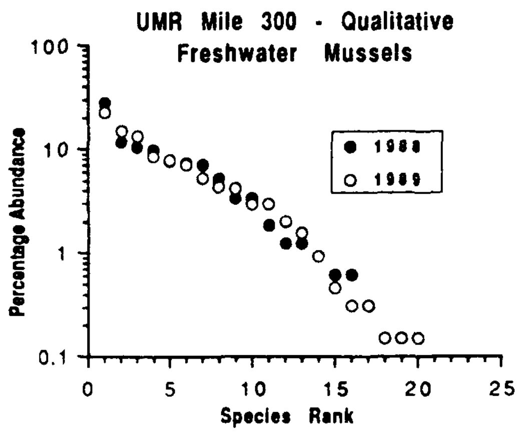
Figure 14. Total density of mussels in 1988 and 1989



a. Quantitative samples, RM 505



b. Qualitative samples, RM 505



c. Qualitative samples, RM 299

Figure 15. Percentage abundance versus species rank in 1988 and 1989

These differences could also have been the result of sampling slightly different portions of the bed or unequal sampling intensity.

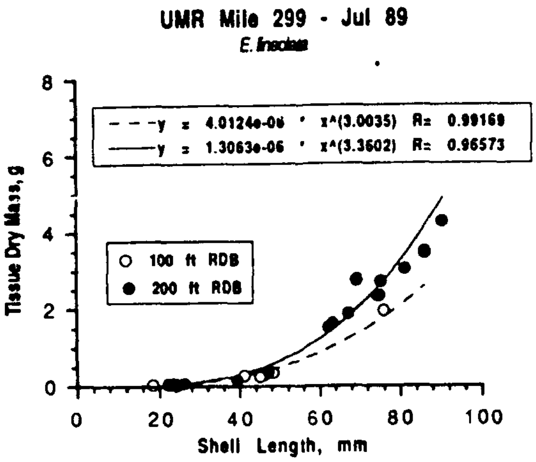
Individual Condition

39. An analysis of clam condition involves determining relationships between shell length (SL), the components of shell dry mass (SDM), and tissue dry mass (TDM). The relationship of SL to SDM and TDM can be species-specific and is sometimes distinctive between populations within a species. Shell mass is non-living material that is not removed until death, although small quantities can be lost by erosive action of high-velocity water. Tissue mass

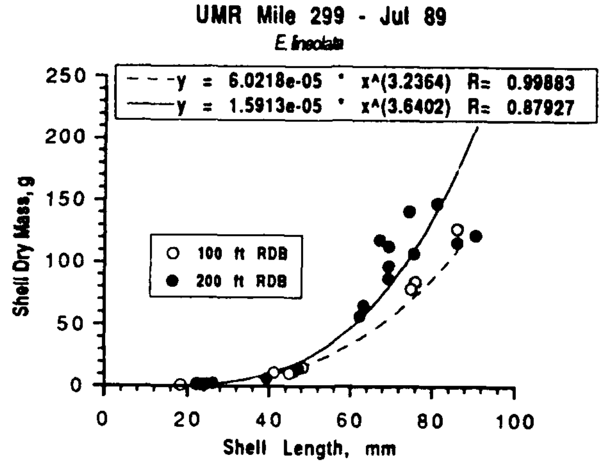
represents most of the energy (caloric) component of the standing crop biomass of standard ecological studies. The relationship between shell mass and tissue mass provides an index of the relative robustness of the tissue for a species population. These relationships are important baseline indicators of animal condition. The ratio of tissue mass to shell length can vary seasonally or with respect to reproductive condition. The ratio of shell mass to shell length can be affected by calcium content of the water, or by erosion, which usually is more noticeable in older animals. These condition indices could also be affected by environmental disturbance.

40. These data on physical condition can be used to interpret effects of commercial traffic. If vessel movement causes substrate scour, shells could be eroded and relationships between shell length and shell mass could differ from baseline conditions. If increased frequency of turbulence at the substrate-water interface negatively affects respiration and metabolism, relationships between shell mass (or length) and tissue mass could be negatively affected (Payne and Miller 1987). Relationships between shell length and tissue dry mass (or shell dry mass) can be expressed as power equations where TDM (or SDM) = aSL^b. As shell length increases, shell mass and tissue mass increase to approximately the third power (i.e., $b = 3$). In the relationship between SL and TDM for *E. lineolata*, $b \geq 3$, whereas for *O. reflexa* and *T.truncata*, $b < 3$ (Figures 16a, 17a, 18a). When comparing b for SL and SDM, *E. lineolata* > *O. reflexa* > *T. truncata* (Figures 16b, 17b, 18b). As SL increases, the robustness of SDM and TDM for *E. lineolata* increase at a slightly greater rate than for the other two species. Differences in these ratios with respect to distance to shore were negligible.

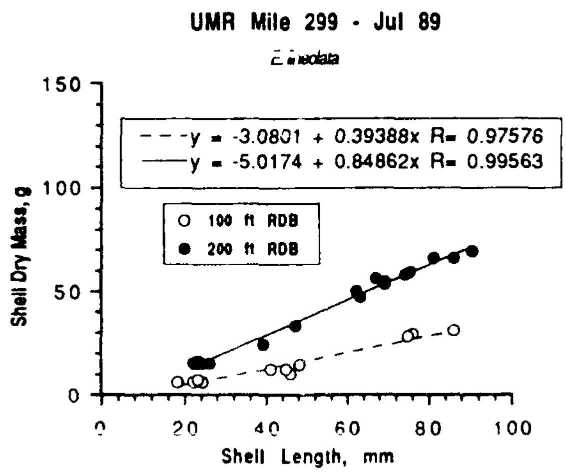
41. The relationship between length measurements (i.e., SL to shell height, SH) are linear, $Y = bx + a$, where b is the slope of the line. The slopes for SL versus SH for two of these species (Figures 17c, 18c) are similar and exhibit no specific trends. There were significant differences in these parameters for *E. lineolata*, which were probably caused by low numbers of individuals and chance interspecific variability. In addition, there are no substantial differences in individual condition between nearshore and farshore sites for either of these unionid species. An illustration of the use of condition indices to evaluate differences in habitat types is depicted in Figures 19a-19c. The relationship between shell length and tissue dry mass, shell dry mass, and shell width was not significantly different ($p > 0.05$, analysis of covariance) between these two populations of *A. plicata*.



a. Tissue dry mass versus shell length

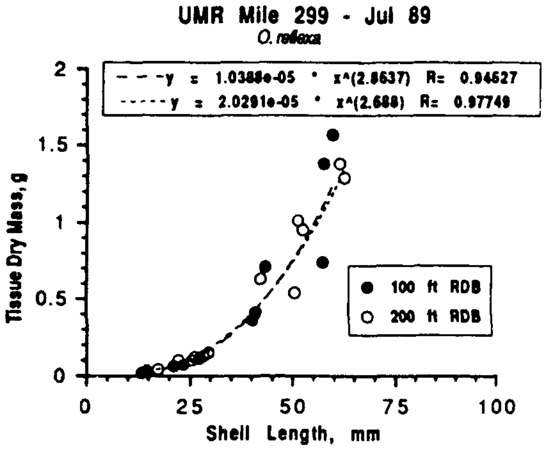


b. Shell dry mass versus shell length

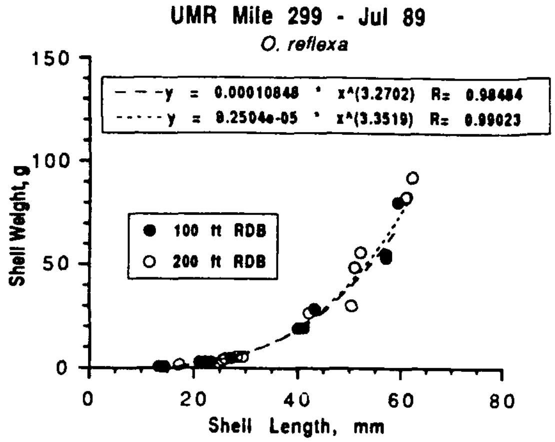


c. Height versus shell length

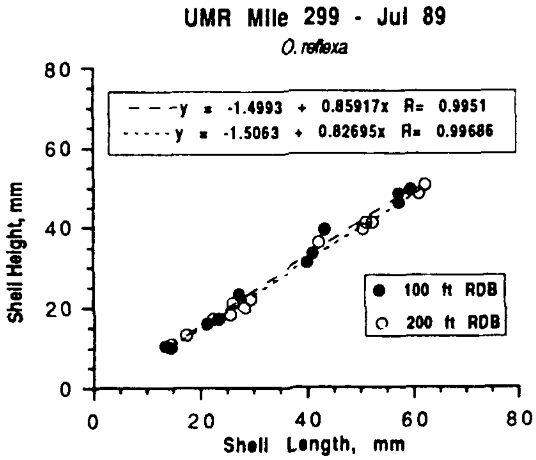
Figure 16. Relationships between shell length, tissue dry mass, shell dry mass, and height for *E. lineolata*



a. Tissue dry mass versus shell length

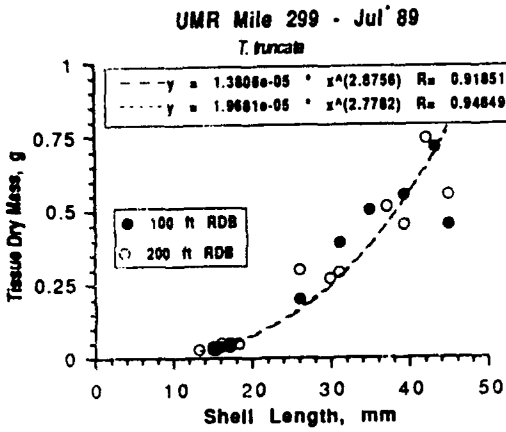


b. Shell weight versus shell length

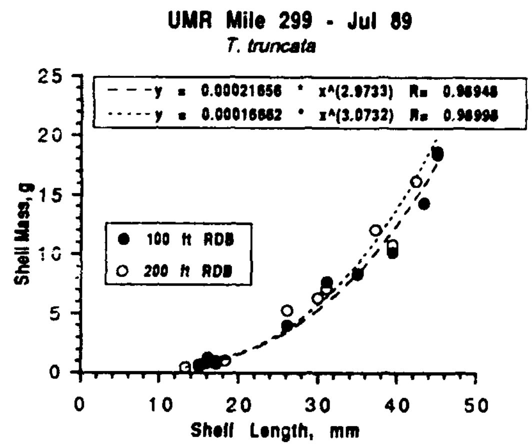


c. Shell height versus shell length

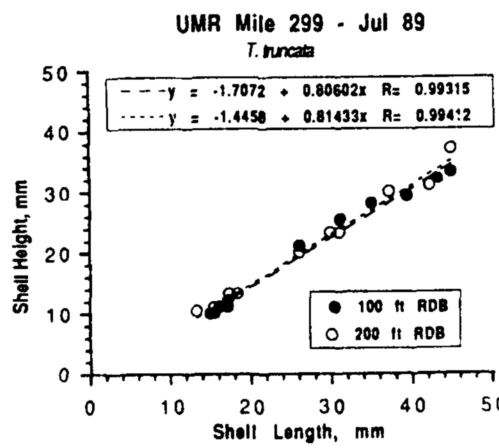
Figure 17. Relationships between shell length, tissue dry mass, shell dry mass, and height for *O. reflexa*



a. Tissue dry mass versus shell length

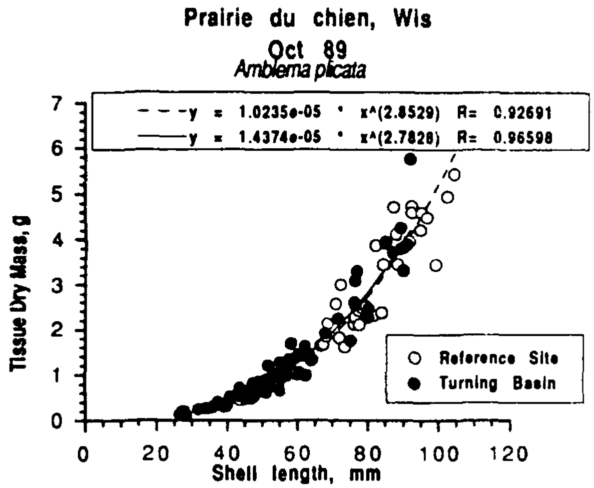


b. Shell mass versus shell length

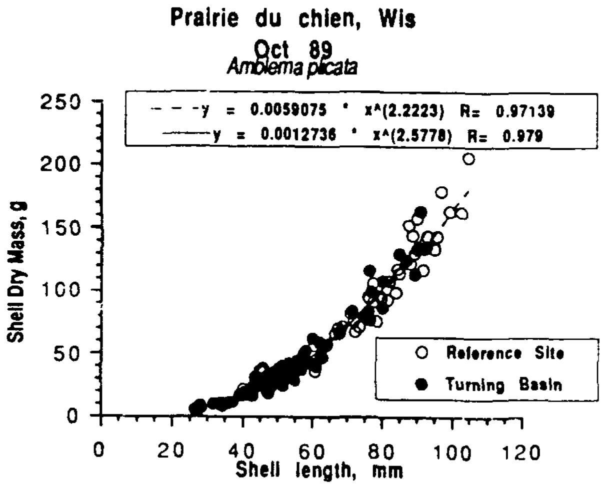


c. Shell height versus shell length

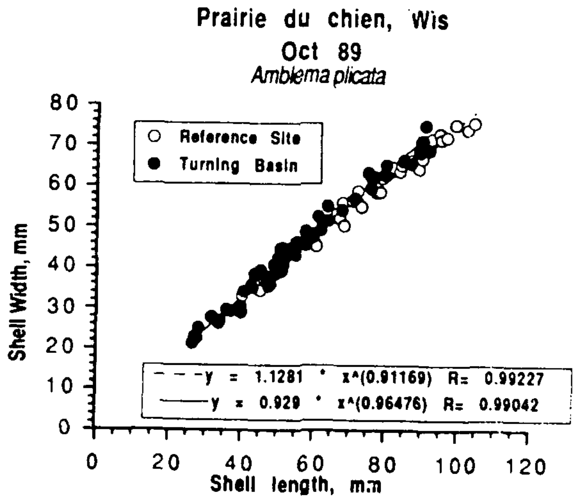
Figure 18. Relationships between shell length, tissue dry mass, shell dry mass, and height for *T. truncata*



a. Tissue dry mass versus shell length



b. Shell dry mass versus length



c. Shell width versus shell length

Figure 19. Relationships between shell length, tissue dry mass, shell dry mass, and shell width for *A. plicata*

Additional monitoring would be required to determine if barge traffic in this area is affecting tissue condition.

Patterns of Size Demography of Abundant Populations In Pool 24

42. In general, pool 24 mussel assemblages, both nearshore (100 ft from LDB) and farshore (200 ft from LDB) were characterized by a very low abundance of old individuals and a high abundance of relatively young mussels. However, some noteworthy nearshore-farshore differences were evident in the strength of particular year classes of recent recruits. Most species exhibited stronger recent recruitment at the farshore than at the nearshore site. *Ellipsaria lineolata* exhibited greater recruitment of the spring 1987 cohort (possibly including the spring 1986 cohort) at nearshore versus farshore sites.

Amblema plicata

43. The three-ridge has a massive shell (adult shell-to-tissue dry mass ratio = 28) and grows to relatively large maximum size. The largest adults in most populations were approximately 100 mm SL (corresponding to 250 g dry mass) and 15 years in age. Among a total of 121 individuals obtained from the nearshore and farshore sites combined, only eight specimens were larger than 50 mm SL (Figure D1). The predominant cohort with median SL equal to 15 mm was comprised of juveniles that probably settled in the summer of 1987. This year class was the prevalent feature of the size structure of both nearshore and farshore assemblages and accounted for 84 percent of the *A. plicata* in the pool 24 bed.

Ellipsaria lineolata

44. The butterfly has a massive shell (adult shell-to-tissue dry mass ratio = 40) but grows to somewhat smaller maximum size (approximately 90 mm SL and 150 g dry mass) than *A. plicata*. A single cohort of small individuals (SL range = 16 to 32 mm, median SL = 25 mm) comprised 49 percent of the total abundance of *E. lineolata* (Figure D2). This cohort probably represents spring 1988 recruitment to the population. Although this cohort was more abundant than any other age group, the *E. lineolata* population included a substantial number of older and larger mussels ranging from 32 to 96 mm SL. Cohort structure could not be distinguished among mussels larger than 32 mm SL. Mussels ranging from 32 to 58 mm SL comprised 54 percent of the nearshore assemblage (Figure D3) as compared with 6 percent of the farshore assemblage (Figure D4). This difference indicates that spring 1987 (or perhaps spring 1987 plus spring

1987 plus spring 1986) recruitment was relatively strong at the nearshore site but weak at the farshore site. In contrast, recruitment of *E. lineolata* at the farshore sites was stronger than at the nearshore site in spring 1988.

Leptodea fragilis

45. The fragile papershell was obtained in sufficient numbers (61 individuals) for size demographic analysis only at the farshore site. This relatively thin-shelled species (adult shell-to-tissue dry mass ratio = 7), exhibits rapid growth and is short-lived. Approximately 3 to 4 years is probably the maximum age for a large adult (110 mm SL and 40 g dry mass). The abundant cohort of *L. fragilis* ranging in SL from 40 to 747 mm probably represents individuals that settled in spring 1988 and are thus slightly more than 1 year old (Figure D5). The less abundant cohort ranging in SL from 80 to 102 mm probably represents 1987 recruits that are slightly more than 2 years old. Spring 1989 recruits were probably nearly all too small to be retained in samples taken in July 1989. The single individual with SL equal to 15 mm probably was a spring 1989 recruit, and the individual with SL equal to 31 mm could have been a large 1989 recruit or a small 1988 recruit.

Obliquaria reflexa

46. The threehorn has a massive shell (adult shell-to-tissue dry mass ratio = 41) but does not grow to large size. The maximum size of *O. reflexa* is rarely greater than 65 mm SL, corresponding to 100 g dry mass). The pool 24 population of *O. reflexa* was comprised almost entirely of four size groups of approximately equal abundance that appeared to represent consecutive year classes of recruits from spring, 1988, 1987, 1986, and 1985 (Figure D6). A single large individual (approximately 70 mm SL) was obtained in the sample of 134 mussels. This represents the approximate maximum size of *O. reflexa* in the UMR and this individual probably settled in spring, 1984. A difference was noted between nearshore and farshore populations in terms of the size demography. The nearshore assemblage (Figure D7) had high abundance of the 1^+ and 4^+ age classes relative to the farshore population (Figure D8).

Truncilla donaciformis

47. The fawn's foot has a relatively elongate shell (adult shell-to-tissue dry mass ratio = 23) but does not grow to a large size (approximate maxima equal 30 mm SL and 7 g dry mass). The largest *T. donaciformis* obtained among 167 individuals was approximately 31 mm SL (Figure D9). All except seven individuals were less than 22 mm SL; this abundant cohort of small

mussels probably represented summer, 1988 recruitment (i.e., was approximately 1 year old). Those mussels greater than 24 mm SL probably represented the few survivors of the summer, 1987 recruitment cohort. The demography of nearshore and farshore assemblages was virtually identical.

Truncilla truncata

48. The deertoe has a massive shell (adult shell-to-tissue dry mass ratio = 23), and is less elongated and grows larger than the congeneric *T. donaciformis* but is nonetheless a relatively small mussel. The approximate maximum size of adult *T. truncata* equals 55 mm SL and 25 g total dry mass. The size demography of the *T. truncata* population in pool 24 indicated an abundant year class of 1988 recruits as well as moderately abundant 2- and 3-year-olds resulting from recruitment in 1987 and 1986, respectively (Figure D10). A few individuals greater than 50 mm SL were obtained that appeared to be too large to be part of the cohort of 3-year-old mussels, suggesting that a few individuals have longevity of 4 years. The nearshore assemblage (Figure D11) of *T. truncata* exhibited stronger recruitment of the smallest cohort (1988 year class) than the farshore assemblage (Figure D12).

Patterns of Size Demography of Abundant Populations In Pool 14

49. Population demography of abundant mussels at pool 14 sites contrasted greatly with that observed at pool 24 sites. Large and relatively old mussels were abundant in pool 14 but these individuals were virtually absent at sites in pool 24. At the bed in pool 14, nearshore and farshore assemblages had virtually identical size demography.

Amblema plicata

50. The three-ridge population at pool 14 was comprised of multiple cohorts spanning the range of possible sizes and ages of this relatively long-lived species, although some recent year classes were not represented at all or in high abundance (Figure D13). The 1987 year class (16-24 mm SL) was present in substantial abundance. Nine mussels ranging in SL from 34 to 40 mm were obtained, and these individuals probably represented 1985 recruits. The lack of small mussels in the size ranges of 24-34 mm SL suggests that 1986 recruitment was weak relative to 1987 and 1985. The most abundant mussels in the population were older and larger, representing multiple cohorts ranging in SL from 48-110 mm. Thus, occasionally strong recruitment and survival to large adult size were characteristics of this *A. plicata* population.

Obliquaria reflexa

51. The three-horn population was comprised mostly of individuals 32-44 mm SL that appeared at the center of a unimodal distribution of individuals ranging from 16 to 60 mm SL (Figure D14). This large size range was not the result of a single age class with extremely variable growth rate. The unimodal distribution was probably caused by several adjacent age classes of unequal abundance with an intermediate age group dominating those of both lesser and greater SL. It is probable that this population included very low abundance of individuals of 1+ age class (expected SL = 12-22 mm based on Figure D4a), slightly greater abundance of 4+ or older age class (>52 mm expected SL), a moderately abundant 2+ age class (22-38 mm expected SL), and an abundant 3+ age class (38-50 mm expected SL). When adjacent cohorts are of highly unequal abundance, the less abundant of each pair often appears as a "tail" of the more abundant cohort. If the pool 14 population of *O. reflexa* was comprised of the cohorts in relative abundance as suggested above, the 1+ age class simply appeared as a tail of the lower end of the size distribution of the 2+ age class, the 2+ age class appeared as a tail of the lower end of the size distribution of the 3+ age class, and 4+ or older age classes appeared as tails of the upper end of the size distribution of the dominant 3+ age class.

Obovaria olivaria

52. The hickory nut was obtained in sufficient number (43 individuals) for analysis of size demography only at the farshore site. *Obovaria olivaria* has a very massive shell (adult shell-to-tissue dry mass ratio = 41) and grows to moderate size (approximate maxima equal 65 mm SL and 100 g total dry mass) Moderately large *O. olivaria* (38-56 mm SL) comprised 74 percent of the assemblage at the farshore site (Figure D15). All of the individuals in this size range may have resulted from a single year of strong recruitment. Large individuals (58-74 mm) accounted for 23 percent of this population; a single small mussel (19 mm SL) was also obtained.

Quadrula pustulosa

53. The pimpleback has a very massive shell (shell-to-tissue dry mass ratio = 39) and grows to moderately large size (approximate maxima equal 65 mm SL and 100 g total dry mass). A mix of cohorts ranging from small recent recruits to large adults was evident in the demography of *Q. pustulosa* (Figure D16). Not all cohorts could be distinguished in the SL frequency histogram due to the uneven abundance of adjacent groups. The median SL of the most abundant cohort was approximately 50 mm, indicating the abundance of

moderately large and old mussels in this population. Strong recruitment during all recent years was indicated by the moderate abundance of all SL classes from 15 to 40 mm. Peak abundance of these recent recruits was indicated clearly at 36-40 mm SL, and less clearly at 28-32 mm SL and 20-22 mm SL. A fourth peak at 14-16 mm was also barely evident, but this SL class included so few individuals (four) that it is potentially misleading to interpret this as the median SL of a cohort. It is possible that these three other peaks represent recruitment classes of 1985 (median SL = 37 mm), 1986 (median + SL = 30 mm), and 1987 (median SL = 21 mm). The spacing of these probable cohorts averages 8 mm. The annual increment of SL growth of *Q. pustulosa* has been estimated to equal approximately 9 mm in the lower Tennessee River (Payne and Miller).*

Quadrula quadrula

54. The mapleleaf is a massively shelled species (shell-to-tissue dry mass ratio = 41) that grows to large size (approximate maxima equal 85 mm SL and 175 g total dry weight). The population of *Q. quadrula* in pool 14 was a mix of cohorts ranging from small, young mussels to large, old adults (Figure D17). Individuals greater than 50 mm SL comprised 68 percent of the population, and these larger mussels represented several largely overlapping cohorts. Among mussels less than 50 mm SL, there were two apparent cohorts of recent recruits, one ranging from 16 to 24 mm SL and a second centered at 32-38 mm SL. The broad upper "tail" of this larger cohort extended 50 mm SL and probably masked the occurrence of a cohort of lesser abundance with median SL of 44-50 mm. Despite uncertainty in the precise interpretation of the size demography of the *Q. quadrula* population, it was clear that this species recruits with considerable frequency and strength to maintain a substantial adult population.

Truncilla truncata

55. This population in pool 14, unlike that in pool 24, was not dominated by a cohort that was probably comprised of 1-year-old mussels (i.e., those individuals < 24 mm SL). The 2-year-old cohort (24-38 mm SL) was the most abundant in pool 14 and comprised 52 percent of the population (Figure D18). The 3-year-old group (38-50 mm) and the .-year-old group were approximately coequal in abundance and were evident as weak "shoulders" in the

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* Unpubli hed information, Barry S. Payne and Andrew C. Miller, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

upper and lower tails of the frequency distribution of the dominant cohort of 2-year-old mussels.

Comparisons of 1988 and 1989 demographic patterns

56. The size demography of two species populations showed clear changes from 1988 to 1989. The sample of *A. plicata* from pool 14 collected in 1988 (Figure D19) did not include the 1987 recruitment class that was evident in the 1989 sample (Figure D13). Those individuals that were 16-24 mm SL in July, 1989, were probably 6-14 mm SL in July, 1988 (their recruitment at an approximate SL of < 1 mm was probably in the late summer of 1987). Due to their small size this 1988 year class was barely represented in the first year (a single individual approximately 13 mm SL obtained in 1988 was the only representative of this cohort). A similar difference was observed in the *T. truncata* sample from pool 24 in 1989 (Figure D10) versus 1988 (Figure D20). In 1989, strong recruitment in 1987 was indicated by the abundance of mussels ranging from 16 to 22 mm SL. As with *A. plicata* in pool 14, these 1987 recruits were probably too small (6-12 mm SL) to be obtained in the 1988 samples. In addition, differences noted in the 1988 and 1989 demography of *T. truncata* in pool 24 indicated that SL increased approximately 12 mm during growth from the age of 1 to 2 years, and the annual increment of SL increase was 6 mm from ages 2 to 3 years.

PART IV: PHYSICAL EFFECTS OF VESSEL PASSAGE

Changes in Water Velocity

Preliminary investigations

57. In 1989, water velocity data were collected near RM 505 in pool 14, and in the main channel near RM 635 in pool 10. Physical data are collected at sites where biotic parameters (density, species richness, population structure, etc.) are monitored. Biological and physical effects data will be collected at each of the five mussel beds chosen for detailed study (Table E1).

58. In velocity Test 2 (Figure E1) data were collected before and after a 21-ft skiff passed over the nearshore sensor (180 ft from LDB). The skiff had little or no effect on ambient water velocity; these data are being discussed to illustrate the experimental design and type of information that was obtained. Water velocity data were collected at 1-sec intervals for a total of 84 sec. The 21-ft skiff passed downriver (note the position of the arrow on Figure E1) 40 sec after the test began. Data were collected about 25 cm above the substrate-water interface at a nearshore (180 ft LDB) and farshore (400 ft LDB) site.

59. Mean water velocity parallel to flow (the X component) was slightly lower at the nearshore site (0.533 ft/sec) than at the farshore site (0.620 ft/sec). Mean velocity at right angles to flow (the Y component) was -0.226 and 0.045 fps at the nearshore and farshore sites, respectively. This component of flow, although at or near zero under ambient conditions, can be affected by up and downbound commercial tows. Standard deviations (SDs) for all four of these velocity readings were similar and ranged from 0.047 to 0.062. The SD provides a means of estimating turbulence; high values indicate considerable fluctuation about the mean. Water velocity perpendicular to flow exhibited slightly higher SD readings than data collected parallel to flow. Minimum (Min), maximum (Max), and range (Max-Min) for all four velocity measures are listed below. The range in velocity was slightly greater perpendicular to flow than parallel to flow.

Test 2

	Nearshore		Farshore	
	Perpendicular	Parallel	Perpendicular	Parallel
Mean	-0.226	0.533	0.045	0.620
SD	0.062	0.054	0.050	0.047
Min	-0.414	0.376	-0.053	0.508
Max	-0.055	0.635	0.170	0.715
Range	0.359	0.259	0.223	0.207

60. Combined velocity was calculated from the X and Y components of flow (Figure E1). Mean combined velocity at the nearshore and farshore sites was 0.583 and 0.624 fps, respectively. The range and SD were slightly less at the farshore than at the nearshore site. The direction of flow can be calculated from the components of velocity and the position of the sensors. At both nearshore and farshore sites the river flowed south; i.e., approximately 200 deg from north (0 or 360 deg). The range in direction of flow, 34.3 and 20.0 deg, at nearshore and farshore sites, respectively, is minimal. A summary of these statistics appears below:

Test 2

	Nearshore		Farshore	
	Combined Velocity	Flow Direction	Combined Velocity	Flow Direction
Mean	0.583	207.945	0.624	210.810
SD	0.053	6.307	0.047	4.594
Min	0.439	191.000	0.520	200.000
Max	0.688	225.300	0.732	220.000
Range	0.249	34.300	0.212	20.000

Ambient conditions

61. Approximately 200 sec of continuous water velocity data were collected under ambient conditions (i.e., no navigation vessels were present) at RM 505 (Figure E2, Test 1). The mean (±SD) velocity parallel to flow at the nearshore and farshore sites was 0.454 ±0.074 and 0.632 ±0.048 fps, respectively. Mean velocity perpendicular to flow was -0.189 ±0.063 and 0.070 ±0.050 fps, at the nearshore and farshore sites, respectively (see Table E2). Mean combined velocity was 0.495 ±0.078 and 0.638 ±0.047 fps, respectively.

Direction of combined flow varied only slightly at the nearshore (189.6 to 226.2 deg) and farshore (200.0 to 224.0 deg) sites.

62. Ambient conditions at RM 635, pool 10 of the UMR at a nearshore and farshore site on the left and right descending banks are depicted in Figures E3 (Test 15) and E4 (Test 16), respectively. Nearshore mean velocities under ambient conditions (0.362 ±0.053 on the LDB, Figure E3, Test 15) and 0.311 ±0.056 on the RDB (Figure E4, Test 16), respectively, were slightly less than values obtained at nearshore sites in pool 14. However, at the farshore site along the LDB at RM 635, there was greater fluctuation in ambient velocity than at the nearshore site. Mean velocity at the farshore site on the LDB (Figure E3, Test 15), 0.383 ±0.527 fps, had an SD approximately 10 times greater than the nearshore site. Conditions at the farshore site on the RDB (0.356 ±0.064 fps) were only slightly more variable than at the nearshore site (Figure E4, Test 16). Data collected on the right descending bank have the X and Y components of flow reversed.

63. Tests 1, 15, and 16, as depicted in Figures E2, E3, and E4, with summary statistics in Table E2, illustrate normal fluctuation in velocity and direction of flow under ambient conditions. Velocity parallel to flow was usually about 0.4 fps at the nearshore site and slightly greater at the farshore site. Velocity at right angles to flow was about 0.0 fps at both sites. There was some fluctuation in direction and magnitude of flow under ambient conditions, which increased at greater distances from shore. At the nearshore site the SD was usually less than associated mean values, whereas at the farshore sites, the SD was typically greater than mean values. Direction of flow typically varied by 20 to 40 deg. An understanding of flow under normal conditions (i.e., no vessels present), is necessary to fully interpret the effects of vessel passage.

64. At the mussel bed in pool 14, water velocity data were collected at a nearshore site (either 180 or 400 ft from the LDB) and a farshore site (either 400 or 500 ft from the LDB). The densest portion of the mussel bed was 160 ft from the LDB and it did not extend much beyond 400 ft from the LDB (Figure 9). In pool 10, water velocity data were collected in the main channel at distances of 125 and 260 ft from the LDB. Mussels were found at the nearshore site although densities were less at the farshore site. On the RDB, water velocity data were collected at distances of 100 and 200 ft from the RDB. Mussel densities were estimated at 110.2 individuals/sq m at the

nearshore site (115 ft from the RDB) and 64.6 individuals/sq m at the farshore site (180 ft from the RDB, see Table 6).

Downbound vessel passage
resulting in little or
no measurable effect on velocity

65. Two examples of little or no measurable change in water velocity as a result of downbound vessel passage are illustrated in Tests E3 and E9. Test 3 (Figure E5) depicts the effects of two 21-ft skiffs (each with a 100-hp engine) moving downriver. They passed on either side of the nearshore buoy, were approximately 180 ft from the LDB, and in water 10 ft deep. Inspection of Figure E3 indicates that there was a very slight decrease in current parallel to flow after the vessels passed. Examination of Table E2 indicates that mean, SD, and range in velocity at the nearshore and farshore sites were similar to ambient conditions. Hence the passage of these skiffs had little or no measurable effect on water velocity near the substrate-water interface.

66. In Figure E6 (Test 9) the effects of a downbound tow, 1,000 ft from the LDB, are illustrated. At the nearshore site both components of velocity, in addition to combined flow and direction, were unaffected. In addition, mean and SD for water velocity at the nearshore and farshore sites (0.356 $\pm$ 0.045 and 0.506 $\pm$0.065, respectively) were similar to ambient conditions. At the farshore site, there was a slight decline in velocity for about 100 sec (starting before the barge passed). At the farshore site, the component of velocity parallel to flow declined from a maximum of 0.658 fps to a minimum of 0.341 fps. The combined velocity at the farshore site also declined, although there was no effect on direction of flow.

Minor effects of downbound tows

67. Illustrations of minor, although measurable effects of downbound tows are depicted in Figures E7 (Test 8) and E8 (Test 13). In Test 8, a downbound tug and 15 barges passed 600 ft from the LDB. The component of velocity parallel to flow declined from slightly more than 0.4 fps to a minimum of 0.159 fps (Table E2). The component of velocity perpendicular to flow exhibited a moderate increase. The entire event lasted for about 200 sec. The farshore velocity was affected in the same manner (although to a slightly greater degree) than nearshore velocity. Combined flow at the nearshore and farshore sites exhibited a small (about 0.2 fps) decrease in velocity that began before the vessel passed and lasted for 50-100 sec. At both the nearshore and farshore sites, the water moved slightly east (toward the LDB, see

Figure 2) after the vessel passed. The flow then shifted west (toward the channel) before stabilizing.

68. Test 13 included two events; Figure E8 depicts the second event (400 sec from the start) in which the vessel passed 450 ft from the LDB. As with the previously described event (Test 8) the velocity component parallel to flow declined while the component perpendicular to flow exhibited a minor increase. The combined velocity declined sharply, returned to slightly greater than mean velocity, then declined briefly again. Within a few seconds of passage there was considerable fluctuation in velocity that was probably caused by vessel passage. Vessel movement caused near current reversal for about 100 sec. The direction abruptly changed from about 180 deg (i.e., the river flows south, see Figure 2), turned counterclockwise (toward the east), and flowed north at about 0.5 fps. There was only a minor current reversal at the near- and farshore sites for Test 8 (Figure E7).

Effects of upbound tows

69. The effects of four upbound tows are illustrated in Figures E9 (Test 6), E10 (the first vessel of Test 13), E11 (Test 7), and E12 (Test 5). None of these upbound tows caused a sharp decline in velocity parallel to flow (for example, see Figure E9). In Test 6 the velocity component parallel to flow reached maximums of 0.847 and 0.899 fps at about the time the front of the vessel passed. The combined velocity also exhibited a measurable increase, to maximums of 0.863 and 0.921 fps, respectively. Little or no detectable change in direction of flow was observed. The upbound tow mainly increased water velocity over ambient conditions; no current reversal took place.

70. Figure E10 (the first event of Test 13) illustrates a minor effect of vessel passage that was different from Test 6. Immediately ahead of the tow, the velocity parallel to flow decreased from about 0.5 fps to about 0.2 fps. Combined flow also declined slightly, although there was no increase in velocity (additive effect) as the vessel passed. As with Test 6, there was no measurable effect on direction of flow. The decrease in velocity was probably the result of a surge wave which preceded the vessel.

71. Figure E11 (Test 7) depicts an upbound tow that was 750 ft from the LDB. Passage of this vessel had little or no measurable effect on single velocity components, combined velocity, or direction of flow. An examination of summary statistics for this event illustrates that the mean, SD, and range were similar to ambient conditions (Table E2).

72. Figure E12 (Test 5) illustrates the effects of a workboat with two unloaded barges moving upriver at about 600 ft from the LDB. An inspection of both velocity components, including the combined velocity and direction of flow, indicates that there were no measurable effects of passage. In addition, mean, SD, and range for all velocity and direction data were similar to those measured under ambient conditions (Table E2).

Major effects of downbound tows

73. Major effects of downbound tows are illustrated in Figures E13, E14, E15, E16, and E17 (Tests 12; 14, first part; 14, second part; 4; and 10, respectively). Test 12 illustrates the effect of a downbound tug with barges that was about 375 ft from the LDB. The component of velocity parallel to flow declined to about -1.8 fps about 40 sec after the front of the tow passed the sensors. The velocity perpendicular to flow exhibited a moderate increase (see also Figures E7 and E8) that occurred when the X component decreased. At the farshore site both components of velocity exhibited similar declines. The combined velocity increased to about 1.9 fps. The event caused current reversal that lasted about 75 sec. The flow was first directed toward the left descending bank (east), then upriver. There were no extensive fluctuations or disturbances after the vessel passed.

74. Test 14 (Figures E14 and E15) was measured on the RDB in pool 10 (X and Y components are opposite those measured on the LDB). The component of velocity parallel to flow declined rapidly, fluctuated erratically, then declined sharply about 75 sec after the vessel passed. A minor increase in velocity perpendicular to flow was also noted. At the farshore site, the component of velocity parallel to flow declined abruptly. However, both components of flow did not follow a similar pattern as they did at the offshore site in Figure E13 (Test 12). There was a slight increase in the component of velocity perpendicular to flow. The range in velocity at the nearshore site (-0.202 to 0.154 fps) was less than at the farshore site (-0.431 to 439 fps). Flow moved toward the right descending bank (west) and then reversed (flowed upriver) for about 100 sec. This effect is similar to the event depicted in Figure E13 (Test 12) except that since the sensor was on the other side of the river, the flow moved in a different direction. As illustrated by Figure E15, the effects of vessel passage were dissipated rapidly; the event lasted about 500 sec (from sec 50 to sec 550).

75. Test 4 (Figure E16) illustrates a major event with a duration of about 200 sec. The characteristic decline in velocity parallel to flow and

increase in velocity perpendicular to flow were noted at the nearshore site. At the farshore site, the changes to both components of velocity were similar. The response at the farshore site was similar to Test 12 (Figure E13) and different from that in Test 14, first part (Figure E14). Although this event caused a comparatively long-lasting effect, the magnitude of velocity change was less than those depicted in the previously described tests. The range in velocity change was from -0.043 to 0.501 fps at the nearshore site and 0.055 to 0.638 fps at the farshore site. The changes were much less than for Test 12 where the range was -1.791 to 0.598 and -1.236 to 0.941 at the nearshore and farshore sites, respectively. The magnitude of current reversal was much less for this event than the previously described events. At the nearshore site the direction changed from about 180 deg to about 90 deg: at the farshore site, the flow changed only about half that much. The greater distance from the shore for test 4 (560 ft from LDB) as compared with Test 12 (375 ft from LDB) was probably the causative factor.

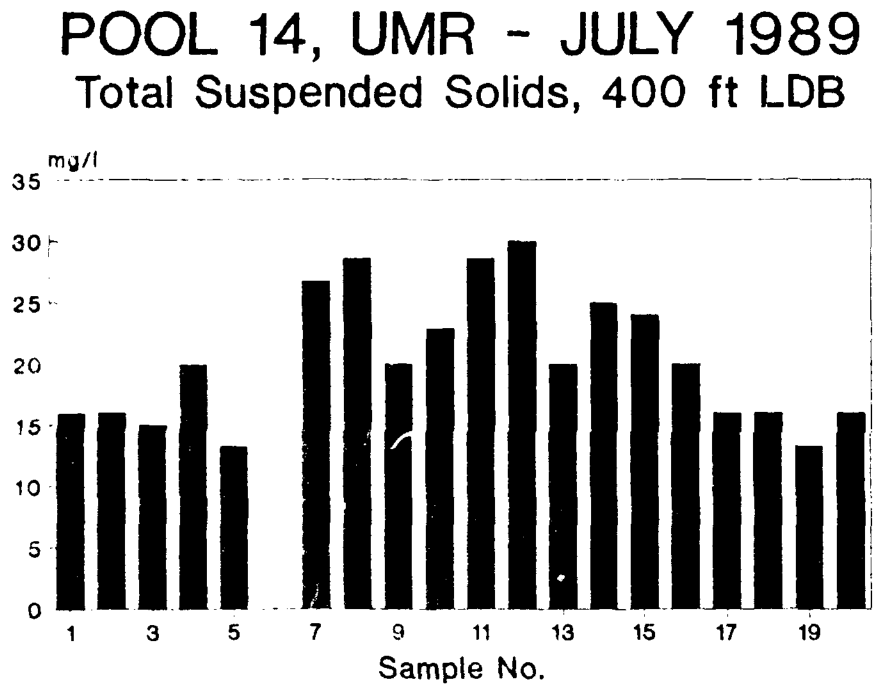
76. Test 10 (Figure E17) was conducted in pool 14, RM 505.5, although for this test the sensors were closer to the main channel than for the previous tests at this location. The nearshore sensor was placed 400 ft from LDB (as compared with 180 ft LDB) and the farshore sensor was at 500 ft LDB (as compared with 400 ft LDB). The minimum and maximum values for each single component, and combined components, were similar to those of previously described events (Figures E16, E13, E14); however, this event was characterized by large fluctuations in velocity after the vessels passed. The effects at the farshore site were still notable 500 sec after the event. Direction of flow shifted east at the nearshore site, then stabilized approximately 100 sec after the vessel passed. At the farshore site the flow moved east, then upriver briefly.

Changes in Suspended Solids

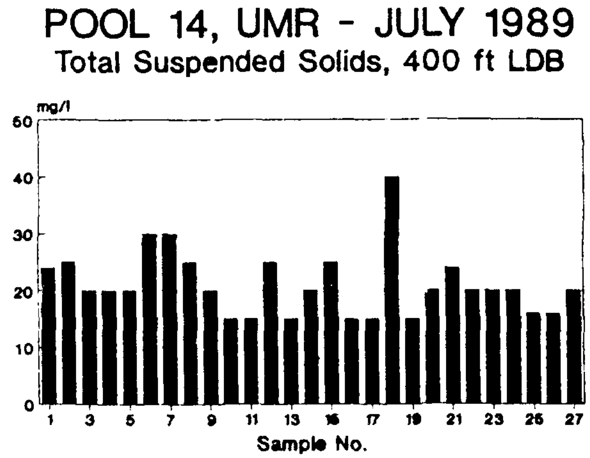
77. For selected vessel passages, a 500-ml bottle was collected from near the substrate-water interface (Figure 5). Bottles could be filled every 15 sec, so it was possible to obtain a nearly continuous record of total suspended solids before and immediately after a commercial vessel passed. During ambient conditions (no vessels in the area), total suspended solids (TSS) varied from 16.0-30.0 mg/ℓ (mean = 20.4 ±5.3, Figure 20a). Minor fluctuations in TSS in large rivers are expected and at least partially due to small

changes in magnitude and direction of flow (see Figures E1, E16, and E17). A passing tug will resuspend sediments that can be collected using these techniques.

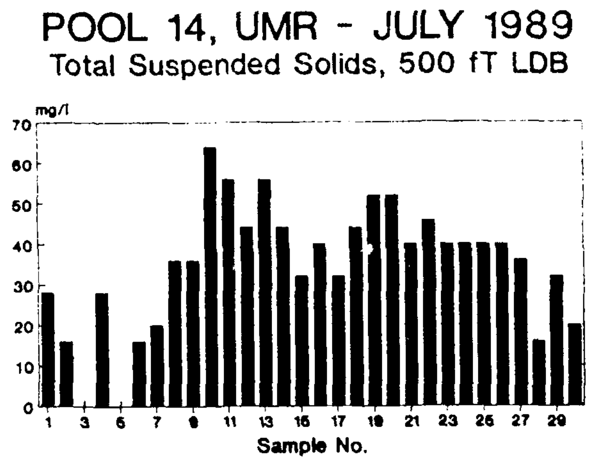
78. An upbound tug passed within 600 ft of the LDB immediately after the third set of water samples were collected (Figures 20b and 20c). Little or no change was noted at the nearshore site, although the variance and mean TSS were higher at the farshore site (mean = 37.4 $\pm$12.4 and 21.1 $\pm$5.7 mg/ℓ at the nearshore and farshore sites, respectively). The range in TSS at the farshore site was 16.0-64.0 mg/ℓ; at the nearshore site, it was 15.0-40.0 mg/ℓ.



a. Pool 14



b. Nearshore site



c. Farshore site

Figure 20. Ambient total suspended solids immediately before and after passage of a commercial vessel

PART V: SUMMARY

79. A monitoring program was initiated in 1988 to assess the effects of commercial navigation traffic on freshwater mussels and the endangered *L. higginsi*. Studies were designed to obtain information on physical effects of commercial vessel passage (changes in water velocity and suspended solids near the substrate-water interface) at dense and diverse mussel beds in the UMR. In addition, important biotic parameters (species richness, species diversity, density, growth rate, population structure of dominant mussel species, etc.) are being monitored every second year at these mussel beds. Biological and physical studies are being coupled so reliable predictions of the environmental effects of vessel passage can be made. Baseline data will be collected until 1994; additional studies will then be conducted until 2040 when commercial traffic is predicted to reach its maximum level. This report discussed baseline data collected during the summer of 1989.

80. In 1989, mussels were collected using qualitative and quantitative (0.25 sq m total substrate) methods at productive beds in pool 24 (RM 299), pool 14 (RM 505), and pool 10 (RM 635). Water velocity and suspended solids concentrations were measured immediately following vessel passage at mussel beds in pools 10 and 14. These data, to include information collected from 1988-94, will be used to assess the effects of commercial navigation traffic on mussels in the UMR.

81. The UMR mussel fauna was dominated by *A. plicata*, which comprised 27.7 percent of the qualitative collection, and was found in 87.1 percent of the samples. Total numbers of the endangered *L. higginsi* were variable; this species comprised slightly less than 0.5 percent of the community and ranked 22nd out of 26 species collected using qualitative methods. Total bivalve density ranged from 31.2 $\pm$25.7 ($\pm$ SD) individuals/sq m to 184.8 $\pm$33.3 individuals/sq m at 24 sites on three beds; with the exception of the bed in pool 24, nearshore densities were about twice as high as farshore densities. Differences in relative species abundance for dominant species, species diversity (1.0-2.3), and evenness (0.38-0.81), with respect to distance from shore, were minor compared to inter-pool differences. Pool 24 mussel assemblages, both nearshore and farshore, were characterized by very low abundance of old individuals and high abundance of relatively young mussels. At sites in pool 14, large and relatively old mussels were abundant and dominated the assemblage; demography of nearshore and farshore assemblages was virtually

identical. With respect to biotic parameters such as relative species abundance, total density, species diversity, and species richness, differences between 1988 and 1989 were minimal.

82. Preliminary water velocity data following vessel passage at two mussel beds were obtained with Model 527 Marsh McBirney meters placed at nearshore (approximately 200 ft from shore) and farshore (approximately 400 ft from shore) sites. Data indicated that a commercial vessel that passes within 500-800 ft from shore can cause a change of 1-2 ft/sec for 50-200 sec immediately above the substrate-water interface near the center of the mussel bed. Changes in suspended solids following vessel passage were minor. It is the purpose of this investigation to monitor the effects of traffic-induced changes in velocity and suspended solids. However, it appears that changes in velocity and suspended solids due to traffic were minor and unlikely to have immediate measurable effects on the mussel community at the study sites.

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Table 1

Summary of Biological and Physical Studies in the Navigation Traffic Effects Study, UMR, 1988-94

Pool	RM	Fiscal Year 88	89	90	91	92	93	94
24	299.6	Qual Quant	Qual Quant		Qual Quant Growth--- Physical	----	Qual Quant ---- Physical	----
17	450.4	Qual Quant		Qual Quant Growth--- Physical	----	Qual Quant ---- Physical	----	Qual Quant ----
14	505.5	Qual Quant	Qual Quant Growth--- Physical	----	Qual Quant ---- Physical	----	Qual Quant ----	----
12	571.4		Qual	Qual Quant Growth--- Physical	----	Qual Quant ---- Physical	----	Qual Quant ----
10 (MC)	635.0	Qual	Qual Quant Growth--- Physical	----	Quant Qual ---- Physical	----	Quant Qual ----	----

Notes: Quant = quantitative samples.
Qual = qualitative samples.
Growth = marked mussels are placed for analysis of rate of growth.
Physical = measures of water velocity and total suspended solids following passage of a commercial vessel.
MC = main channel.

Table 2

Quantitative and Qualitative Mussel Collections in the UMR, 1989

River Mile	Distance to shore, ft	Depth ft	Qualitative Samples	Quantitative Samples
		10 July 1989, Pool 24		
299.5R	220	15	6	--
299.7R	220	15	12	--
299.7R	180	10	12	--
298.5R	200	10	12	--
		11 July 1989, Pool 24		
299.4R	100	10	--	30
299.4R	200	15	--	30
		13 July 1989, Pool 14		
504.8L	160	10	--	30
		14 July 1989, Pool 14		
504.8L	400	19	--	5
504.8L	300	15	--	30
504.8L	100	7	--	5
		15 July 1989, Pool 14		
505.2L	200	15	--	5
504.6L	200	15	--	5
504.7L	100	7	12	--
504.7L	100	7	12	--
504.6L	300	12	12	--
504.6L	300	12	11	--
504.5L	300	7	12	--
		17 July 1989, Pool 13		
554.3L	100	8	12	--
554.0L	100	8	12	--
554.0L	325	17	12	--
554.1L	370	17	12	--
554.1L	100	10	12	--
540.8R	100	15	12	--
540.6R	100	12	6	--

(Continued)

Table 2 (Concluded)

River Mile	Distance to shore, ft	Depth ft	Qualitative Samples	Quantitative Samples
		18 July 1989, Pool 12		
581.0L	100	10	12	--
581.0L	100	10	12	--
581.0L	180	15	12	--
580.9L	180	15	12	--
581.1L	100	10	12	--
571.4R	100	12	9	--
570.0R	200	12	12	--
		19 July 1989, Pool 12		
570.0R	100	10	12	--
		18 September 1989, Pool 10		
634.7L (MC)*	100	8	--	20
		19 September 1989, Pool 10		
634.7R (MC)	115	10	--	20
634.7R (MC)	180	12		10
		20 September 1989, Pool 10		
634.7R (MC)	180	12	--	10
635.4L (EC)*	200	10	--	10
635.7L (EC)	100	12	--	20
		21 September 1989, Pool 10		
634.7R (MC)	200	12	3	--
634.7R (MC)	80	12	11	--
Total samples			286	230

* For pool 10, MC = main channel; EC = east channel.

Table 3

Relative Abundance (p_i) and Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Qualitative Techniques in the UMR, July and September, 1989*

Species	Individuals	p_i	Samples	f_i
Amblema plicata (Say 1817)	1,237	0.2766	249	0.8706
Truncilla truncata (Lea 1860)	521	0.1165	167	0.5839
Obliquaria reflexa (Rafinesque 1820)	419	0.0937	142	0.4965
Obovaria olivaria (Rafinesque 1820)	353	0.0789	118	0.4126
Megalonaias gigantea (Barnes 1823)	284	0.0635	134	0.4685
Elipsaria lineolata (Rafinesque 1820)	263	0.0588	107	0.3741
Quadrula quadrula (Rafinesque 1820)	246	0.0550	140	0.4895
Lampsilis ventricosa (Barnes 1823)	241	0.0539	119	0.4161
Quadrula pustulosa (Lea 1831)	221	0.0494	111	0.3881
Fusconaia flava (Rafinesque 1820)	206	0.0461	127	0.4441
Potamilus alatus (Say 1817)	103	0.0230	77	0.2692
Ligumia recta (Lamarck 1819)	88	0.0197	54	0.1888
Leptodea fragilis (Rafinesque 1820)	74	0.0165	47	0.1643
Arcidens confragosus (Say 1829)	54	0.0121	47	0.1643
Quadrula metanevra (Rafinesque 1820)	47	0.0105	36	0.1259
Anodonta grandis (Say 1829)	34	0.0076	30	0.1049
Quadrula nodulata (Rafinesque 1820)	20	0.0045	20	0.0699
Strophitus undulatus (Say 1817)	14	0.0031	14	0.0490
Truncilla donaciformis (Lea 1828)	13	0.0029	13	0.0455
Lasmigona complanata (Barnes 1823)	11	0.0025	11	0.0385
Actinonais ligamentina (Lamarck 1819)	10	0.0022	9	0.0315
Lampsilis higginsi (Lea 1857)	8	0.0018	8	0.0280
Toxolasma parvus (Barnes 1823)	2	0.0004	2	0.0070
Fusconaia ebena (Lea 1831)	1	0.0002	1	0.0035
Potamilus laevissima (Lea 1830)	1	0.0002	1	0.0035
Plethobasus cyphyus (Rafinesque 1820)	1	0.0002	1	0.0035

Total bivalves	4,472
Total species	26
Total samples	286

* p_i equals the number of individuals of species i divided by the total number of individuals collected. f_i equals the number of samples in which at least one individual of that species was collected divided by the total number of samples.

Table 4

Summary Statistics for Unionids Collected in 0.25-m^2 Quadrats

In Pool 24, UMR, 1989

Summary by Subsite

River Mile	Subsite	Distance to shore, ft	No. of Species	No. of Samples	Density	SD
299.4R	1	100	12	10	49.6	54.9
299.4R	2	100	9	10	31.2	25.7
299.4R	3	100	10	10	29.6	22.8
299.4R	1	200	17	10	184.8	33.3
299.4R	2	200	13	10	82.4	28.7
299.4R	3	200	16	10	159.6	69.2

Summary by Site

Location	Total Subsites	Total Quadrats	Total Species	Mean	SD
Nearshore*	3	30	15	36.9	37.2
Farshore	3	30	18	115.6	56.4

Analysis of Variance

Comparison	No. of Subsites	No. of Quadrats	F	p
Intrasite				
Nearshore	3	30	0.88	0.4248
Farshore	3	30	7.04	0.0035
Intersite				
Nearshore versus Farshore	6	60	40.85	0.0001

* Nearshore(NS) = 100 ft from RDB; Farshore(FS) = 200 ft from RDB.

Table 5

Summary Statistics for Unionids Collected in 0.25-m^2 Quadrats

In Pool 14, UMR, 1989

Summary by Subsite

River Mile	Subsite	Distance to shore, ft	No. of Species	No. of Samples	Density	SD
505.2L	1	200	13	5	62.4	43.1
504.6L	1	200	9	5	49.6	22.4
504.8L	1	100	12	5	57.6	19.7
504.8L	1	160	17	10	78.4	18.7
504.8L	2	160	17	10	74.8	19.2
504.8L	3	160	13	10	54.8	20.7
504.8L	1	300	19	10	66.0	21.5
504.8L	2	300	17	10	75.6	13.0
504.8L	3	300	10	10	18.0	16.9

Summary by Major Site

Location	Total Subsites	Total Quadrats	Total Species	Mean	SD
RM 504.8 Nearshore*	3	30	19	69.3	21.6
RM 504.8 Farshore	3	30	21	59.1	30.7

Analysis of Variance

Comparison	No. of Subsites	No. of Quadrats	F	p
Intrasite				
RM 504.8, Nearshore	3	30	4.2	0.0252
RM 504.8, Farshore	3	30	31.1	0.0001
Intersite				
RM 504.8, Nearshore versus offshore	6	60	5.5	0.0220

* Nearshore(NS) = 160 ft from RDB; Farshore(FS) = 300 ft from RDB.

Table 6

Summary Statistics for Unionids Collected in 0.25-m^2 Quadrats

In Pool 10, UMR, 1989

Summary by Subsite

River Mile	Subsite	Distance to shore, ft	No. of Species	No. of Samples	Density	SD
EC turning basin	1	500	12	10	65.2	43.9
	2	500	12	10	32.0	11.2
EC reference site	1	200	18	10	83.5	40.6
MC Wisconsin side	1	90	14	10	58.0	28.0
	2	90	16	10	58.0	42.2
MC Iowa side (NS)*	1	115	18	10	112.4	17.0
	2	115	18	10	108.0	39.6
MC Iowa side (FS)	1	180	19	10	76.0	18.0
	2	180	16	10	53.2	20.5

Summary for Major Sites

Location	Total Subsites	Total Quadrats	Total Species	Mean	SD
MC Iowa side (NS)	3	20	20	110.2	29.7
MC Iowa side (FS)	3	20	20	64.6	22.1

Analysis of Variance

Comparison	No. of Sites	No. of Subsites	No. of Quadrats	F	p
Intrasite					
MC Iowa side (NS)	1	2	20	7.0	0.0165
MC Iowa side (FS)	1	2	20	0.1	0.7505
Intersite					
MC Iowa side, near-shore versus farshore	2	4	40	30.27	0.0001

* Nearshore (NS) = 115 ft from RDB; Farshore(FS) = 180 ft from RDB.

Table 7

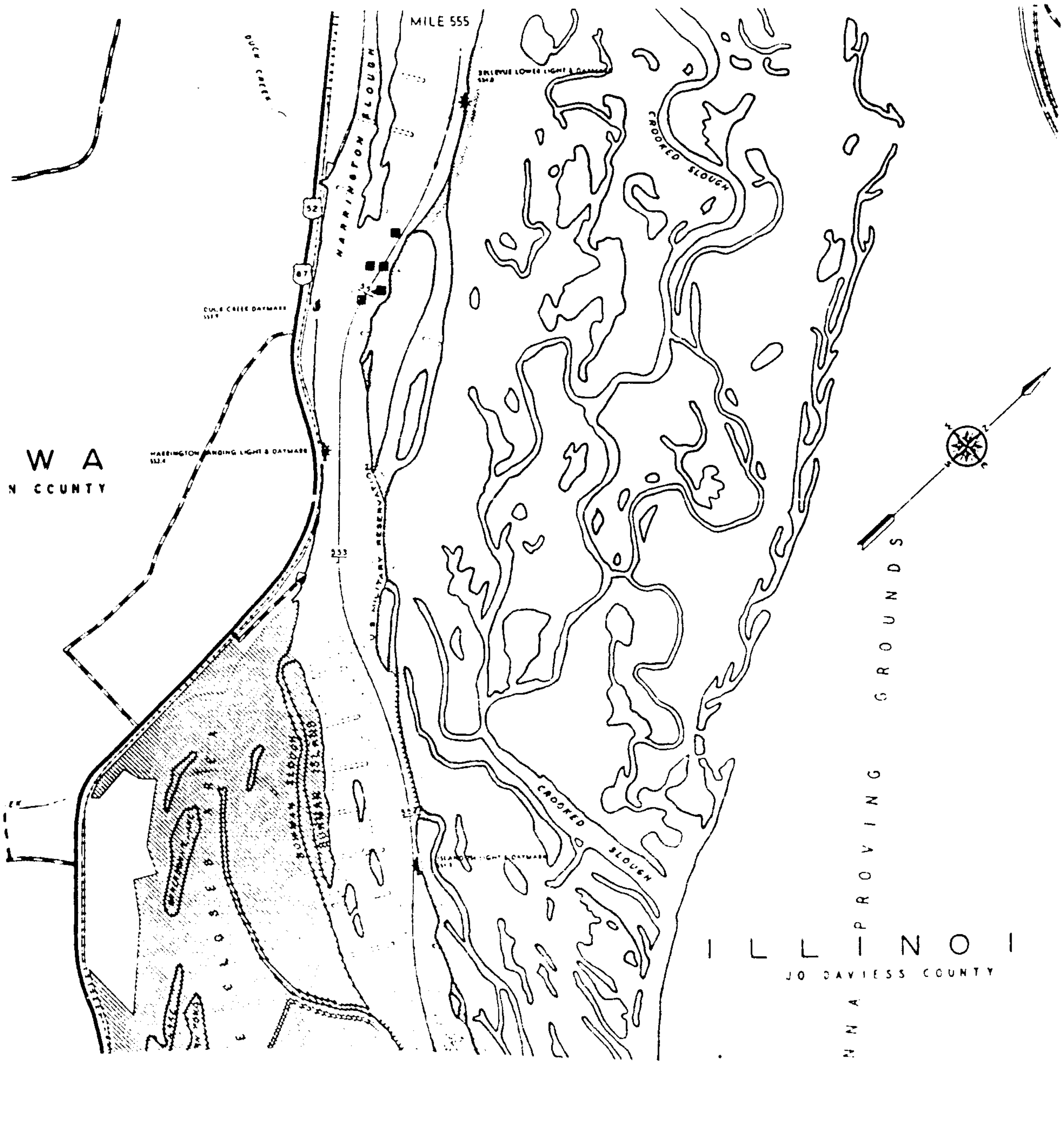
Numbers of *Lampsilis higginsi* Taken in Qualitative and Quantitative Samples at a Productive Mussel Bed in Pool 10 (RM 635) and Pool 14 (RM 505)

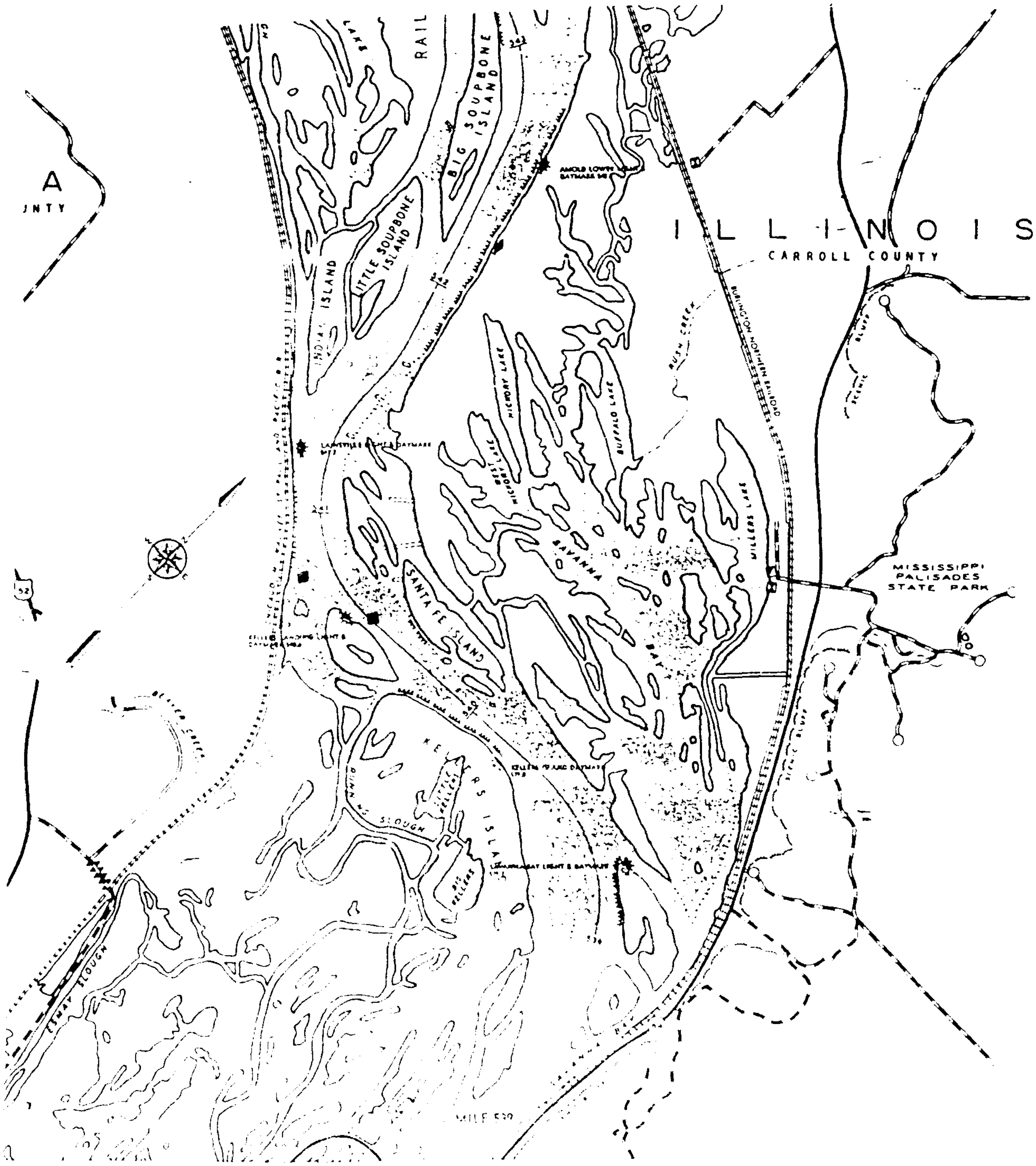
Location	Quantitative			Qualitative		
	Total Mussels	*L. higginsi* Total	*L. higginsi* %	Total Mussels	*L. higginsi* Total	*L. higginsi* %
Pool 14						
1988	253	1	0.40	734	8	1.09
1984	1131	1	0.09	961	5	0.52
Pool 10						
1988	845	2	0.24	699	12	1.72
1984	1616	11	0.68	212	0	--

APPENDIX A

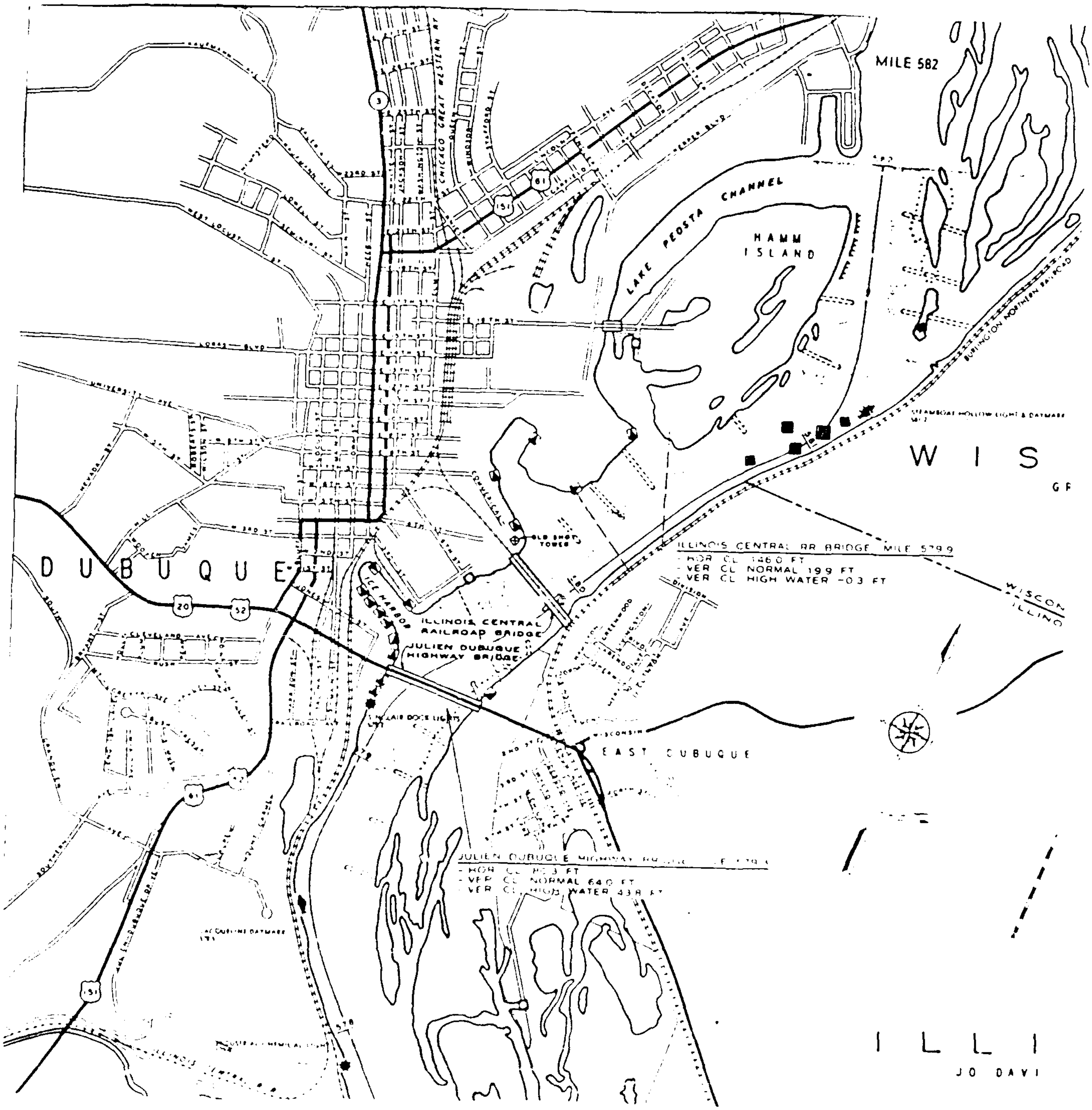
SITES IN THE UMR SURVEYED FOR BIVALVES, 1989

(Note: Although the majority of the preliminary site investigations for this program were conducted in 1988, the following locations were evaluated during 1989. This was done to assist in the site selection process.)

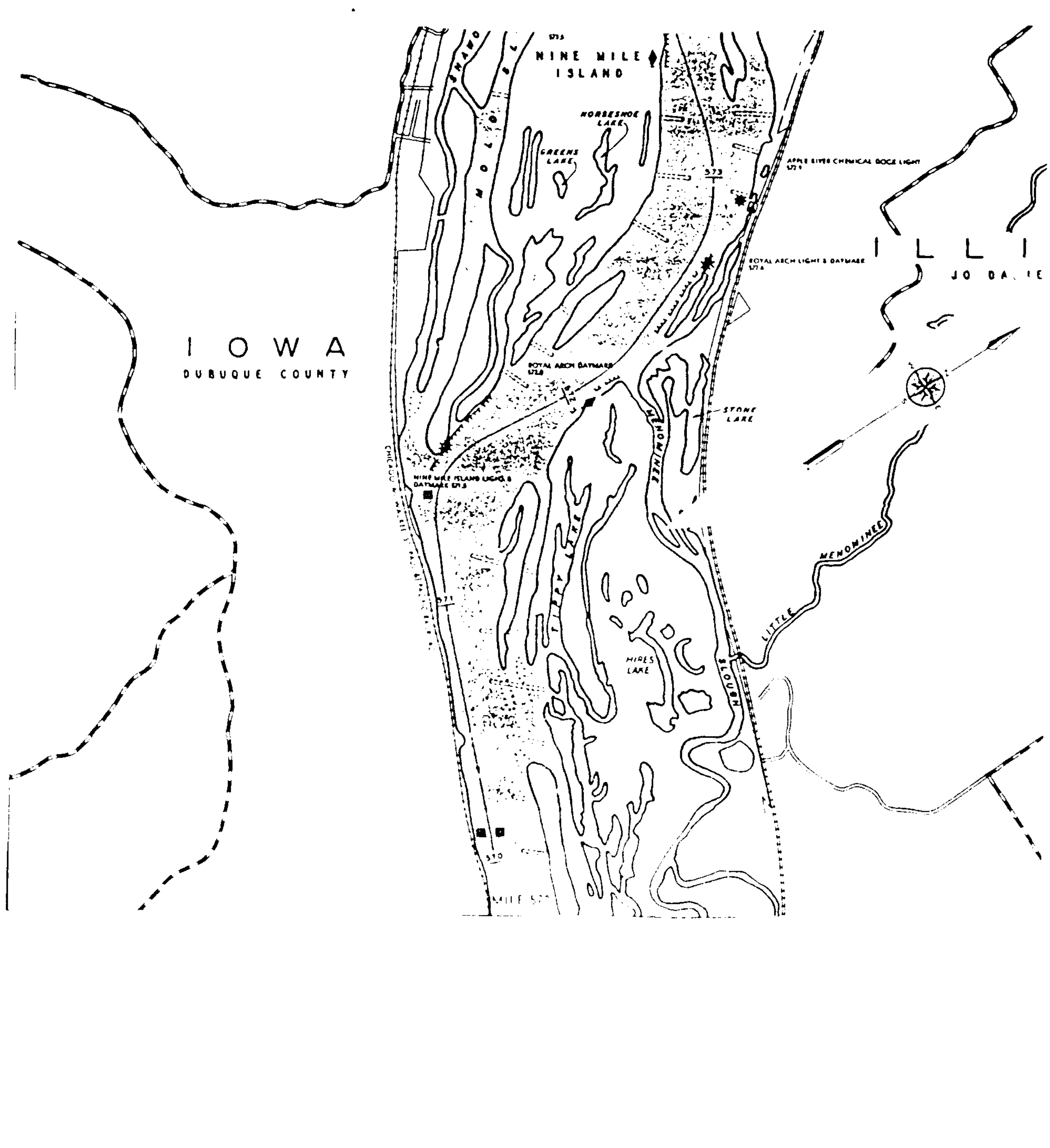

MILE 555
HARRINGTON SLOUGH
CROOKED SLOUGH
W A
N COUNTY
BOWMAN SLOUGH
U.S. MILITARY RESERVATION
I L L I N O I
JO DAVIESS COUNTY
PROVING GROUNDS



ILLINOIS
CARROLL COUNTY
MISSISSIPPI PALISADES STATE PARK
BIG SOUPBONE ISLAND
LITTLE SOUPBONE ISLAND
INDIAN ISLAND
SANTA FE ISLAND
SAVANNA BAY
HICKORY LAKE
WEST HICKORY LAKE
BUFFALO LAKE
MILLERS LAKE
BUSH CREEK
KELLERS ISLAND
SLOUGH
RAIL
A
JNTY



MILE 582
HAMM
ISLAND
LAKE PEOSTA CHANNEL
DUBUQUE
WIS
ILLINOIS CENTRAL RR BRIDGE MILE 579.9
ILLINOIS CENTRAL RAILROAD BRIDGE
JULIEN DUBUQUE HIGHWAY BRIDGE
EAST DUBUQUE
BURLINGTON NORTHERN RAILROAD
ILLI
JO DAVI


NINE MILE
ISLAND
HORSESHOE LAKE
GREENS LAKE
IOWA
DUBUQUE COUNTY
ROYAL ARCH DAYMARK
572.8
STONE LAKE
HIRES LAKE
LITTLE MENOMINEE
SLOUGH
573
571
570

APPENDIX B

FRESHWATER BIVALVES COLLECTED IN THE UMR IN 1989 USING QUALITATIVE TECHNIQUES

Table B1

Relative Abundance (p_i) of Freshwater Mussels Collected Using Qualitative Techniques in the Upper Mississippi River, July and September 1989*

Species	Pool 24				Pool 14				
	299.5R	299.7R	299.7R	298.5R	504.7L	504.7L	504.6L	504.6L	504.5L
A. plicata	0.0896	0.0745	0.1289	0.2060	0.4426	0.3768	0.3687	0.4172	0.3048
T. truncata	0.1045	0.0479	0.0412	0.1558	0.0383	0.0725	0.0303	0.0491	0.0952
O. reflexa	0.0896	0.0426	0.0515	0.1106	0.1093	0.1256	0.2475	0.2086	0.4095
O. olivaria	0.0597	0.0479	0.0567	0.0503	0.0109	0.0097	0.0051	0.0184	0.0048
M. gigantea	0.1642	0.2234	0.1701	0.0553	0.0328	0.0097	0.0051	0.0368	0.0143
E. lineolata	0.1493	0.3085	0.2577	0.1457	0.0164	0.0097	0.0000	0.0123	0.0048
Q. quadrula	0.0448	0.0372	0.0155	0.0754	0.0601	0.0531	0.1061	0.1043	0.0810
L. ventricosa	0.0746	0.0266	0.0309	0.0151	0.0601	0.0242	0.0051	0.0061	0.0048
Q. pustulosa	0.0597	0.0319	0.0464	0.0402	0.1148	0.1787	0.1768	0.0920	0.0571
F. flava	0.0000	0.0266	0.0258	0.0151	0.0383	0.0290	0.0152	0.0368	0.0048
P. alatus	0.0299	0.0266	0.0464	0.0151	0.0219	0.0193	0.0051	0.0000	0.0048
L. recta	0.0149	0.0053	0.0155	0.0050	0.0055	0.0097	0.0000	0.0000	0.0000
L fragilis	0.0896	0.0691	0.0928	0.0704	0.0055	0.0097	0.0000	0.0061	0.0000
A. confragosus	0.0000	0.0000	0.0000	0.0050	0.0164	0.0145	0.0000	0.0061	0.0000
Q. metanevra	0.0149	0.0160	0.0155	0.0151	0.0055	0.0000	0.0000	0.0000	0.0000
A. grandis	0.0000	0.0053	0.0000	0.0050	0.0109	0.0338	0.0051	0.0000	0.0000
Q. nodulata	0.0000	0.0000	0.0000	0.0151	0.0000	0.0048	0.0202	0.0061	0.0095
S. undulatus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T. donaciformis	0.0000	0.0053	0.0052	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
L. complanata	0.0000	0.0000	0.0000	0.0000	0.0000	0.0048	0.0000	0.0000	0.0000
A. ligamentina	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
L. higginsi	0.0000	0.0000	0.0000	0.0000	0.0109	0.0000	0.0101	0.0000	0.0048
T. parvus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0097	0.0000	0.0000	0.0000
F. ebena	0.0149	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0000	0.0000	0.0000	0.0000	0.0048	0.0000	0.0000	0.0000
C. monodonta	0.0000	0.0053	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total individuals	67	188	194	199	183	207	198	163	210
Total species	14	15	14	18	17	19	13	13	7

Species	Pool 13						
	554.3L	554.0L	554.0L	554.1L	554.1L	540.8L	540.6L
A. plicata	0.4158	0.2619	0.1196	0.0935	0.2308	0.1500	0.1132
T. truncata	0.1139	0.3476	0.1483	0.1121	0.0721	0.2000	0.1698
C. reflexa	0.1436	0.1810	0.0287	0.0327	0.0433	0.1550	0.1887
O. olivaria	0.0842	0.0190	0.4498	0.4720	0.1394	0.1100	0.3208
M. gigantea	0.0149	0.0048	0.0000	0.0000	0.0433	0.0200	0.0000
E. lineolata	0.0050	0.0048	0.0287	0.0093	0.0865	0.0300	0.0000
Q. quadrula	0.0644	0.0095	0.0526	0.0280	0.0144	0.1250	0.0943
L. ventricosa	0.0050	0.0286	0.0191	0.0561	0.0625	0.0300	0.0755
Q. pustulosa	0.0347	0.0286	0.0000	0.0374	0.0144	0.0450	0.0000
F. flava	0.0941	0.0810	0.0574	0.0841	0.1010	0.0450	0.0189
P. alatus	0.0000	0.0095	0.0000	0.0047	0.0144	0.0300	0.0000
L. recta	0.0050	0.0095	0.0000	0.0093	0.0433	0.0100	0.0000
L. fragilis	0.0000	0.0000	0.0048	0.0047	0.0000	0.0100	0.0000
A. confragosus	0.0050	0.0048	0.0096	0.0000	0.0769	0.0050	0.0000
Q. metanevra	0.0000	0.0000	0.0766	0.0421	0.0337	0.0000	0.0000
A. grandis	0.0050	0.0048	0.0000	0.0000	0.0096	0.0050	0.0000
Q. nodulata	0.0050	0.0000	0.0000	0.0093	0.0096	0.0100	0.0000
S. undulatus	0.0000	0.0000	0.0048	0.0000	0.0048	0.0050	0.0000
T. donaciformis	0.0000	0.0048	0.0000	0.0000	0.0000	0.0050	0.0189
L. complanata	0.0050	0.0000	0.0000	0.0047	0.0000	0.0100	0.0000
A. ligamentina	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
L. higginsi	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T. parvus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F. ebena	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C. monodonta	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total individuals	202	210	209	214	208	200	53
Total species	15	15	11	15	17	19	8

(Continued)

* p_i equals the number of individuals of species i divided by the total number of individuals collected.

Table B1 (Concluded)

Species	Pool 12								Pool 10	
	581.0L	581.0L	581.0L	580.9L	581.1L	571.4R	570.0R	570.0R	634.7R	634.7R
A. plicata	0.2564	0.2174	0.2262	0.1975	0.1606	0.1224	0.3450	0.4815	0.7333	0.8092
T. truncata	0.1436	0.2609	0.1786	0.1720	0.2694	0.0408	0.0117	0.0159	0.0167	0.0000
Q. reflexa	0.0256	0.0217	0.0238	0.0000	0.0311	0.0612	0.0117	0.0053	0.0000	0.0000
O. olivaria	0.0103	0.0163	0.0179	0.0127	0.0052	0.0612	0.0292	0.0159	0.0167	0.0000
M. gigantea	0.1179	0.1033	0.0833	0.1401	0.0415	0.0306	0.1462	0.1376	0.0000	0.0789
E. lineolata	0.0872	0.0815	0.0833	0.0764	0.0674	0.0000	0.0117	0.0053	0.0000	0.0000
Q. quadrula	0.0564	0.0435	0.0357	0.0318	0.0259	0.0000	0.1111	0.1005	0.0000	0.0197
L. ventricosa	0.1077	0.0761	0.1429	0.1019	0.1554	0.2245	0.0877	0.0476	0.0333	0.0263
Q. pustulosa	0.0410	0.0326	0.0298	0.0255	0.0570	0.0204	0.0175	0.0000	0.0167	0.0066
F. flava	0.0769	0.0598	0.0238	0.0191	0.0725	0.0714	0.0351	0.0265	0.0833	0.0197
P. alatus	0.0154	0.0163	0.0357	0.1083	0.0415	0.0714	0.0175	0.0370	0.0667	0.0263
L. recta	0.0205	0.0380	0.0119	0.0191	0.0415	0.1939	0.0468	0.0635	0.0000	0.0000
L. fragilis	0.0000	0.0000	0.0179	0.0573	0.0052	0.0000	0.0000	0.0000	0.0333	0.0000
A. confragosus	0.0103	0.0109	0.0179	0.0064	0.0000	0.0204	0.0526	0.0265	0.0000	0.0066
Q. metanevra	0.0051	0.0054	0.0060	0.0000	0.0000	0.0000	0.0058	0.0000	0.0000	0.0000
A. grandis	0.0000	0.0000	0.0119	0.0191	0.0000	0.0306	0.0409	0.0106	0.0000	0.0000
Q. nodulata	0.0000	0.0000	0.0000	0.0000	0.0052	0.0000	0.0000	0.0053	0.0000	0.0000
S. undulatus	0.0051	0.0054	0.0298	0.0000	0.0000	0.0000	0.0175	0.0053	0.0000	0.0000
T. donaciformis	0.0051	0.0000	0.0119	0.0064	0.0104	0.0000	0.0000	0.0106	0.0000	0.0000
L. complanata	0.0051	0.0000	0.0060	0.0064	0.0000	0.0102	0.0000	0.0053	0.0000	0.0066
A. ligamentina	0.0103	0.0109	0.0060	0.0000	0.0000	0.0408	0.0058	0.0000	0.0000	0.0000
L. higginsi	0.0000	0.0000	0.0000	0.0000	0.0104	0.0000	0.0058	0.0000	0.0000	0.0000
T. parvus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F. ebena	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C. monodonta	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total individuals	195	184	168	157	193	98	171	189	60	152
Total species	15	17	18	16	16	14	18	17	11	9

Table B2

Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Qualitative Techniques in the Upper Mississippi River, July and September, 1989*

Species	Pool 24				Pool 14				
	299.5R	299.7R	299.7R	298.5R	504.7L	504.7L	504.6L	504.6L	504.5L
A. plicata	0.5000	0.7500	0.9167	0.8333	1.0000	1.0000	0.9167	0.8333	1.0000
T. truncata	0.6667	0.4167	0.5000	0.7500	0.2500	0.5000	0.3333	0.5833	0.6667
O. reflexa	0.5000	0.3333	0.4167	0.8333	0.5000	0.7500	0.8333	0.8333	0.8333
O. olivaria	0.5000	0.5833	0.5833	0.5833	0.1667	0.0833	0.1667	0.2500	0.0833
M. gigantea	0.6667	0.9167	0.9167	0.6667	0.4167	0.1667	0.0833	0.3333	0.2500
E. lineolata	0.6667	1.0000	1.0000	0.8333	0.2500	0.1667	0.0000	0.1667	0.0833
Q. quadrula	0.3333	0.4167	0.1667	0.6667	0.5000	0.5000	0.5833	0.6667	0.7500
L. ventricosa	0.6667	0.3333	0.3333	0.2500	0.4167	0.2500	0.0833	0.0833	0.0833
Q. pustulosa	0.5000	0.4167	0.5000	0.5000	0.6667	0.7500	0.9167	0.5833	0.5833
F. flava	0.0000	0.3333	0.3333	0.1667	0.3333	0.4167	0.1667	0.5000	0.0833
P. alatus	0.3333	0.3333	0.5000	0.2500	0.3333	0.2500	0.0833	0.0000	0.0833
L. recta	0.1667	0.0833	0.1667	0.0833	0.0833	0.0833	0.0000	0.0000	0.0000
L. fragilis	0.6667	0.5000	0.6667	0.5833	0.0833	0.0833	0.0000	0.0833	0.0833
A. confragosus	0.0000	0.1667	0.0000	0.0833	0.1667	0.0833	0.0000	0.0833	0.0000
Q. metanevra	0.1667	0.2500	0.2500	0.2500	0.0833	0.0000	0.0000	0.0000	0.0000
A. grandis	0.0000	0.0833	0.0000	0.0833	0.1667	0.3333	0.0833	0.0000	0.0000
Q. nodulata	0.0000	0.0000	0.0000	0.2500	0.0000	0.0833	0.3333	0.0833	0.1667
S. undulatus	0.0000	0.0000	0.0000	0.0000	0.0833	0.0000	0.0000	0.0000	0.0000
T. donaciformis	0.0000	0.0833	0.0833	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
L. complanata	0.0000	0.0000	0.0000	0.0000	0.0000	0.0833	0.0000	0.0000	0.0000
A. ligamentina	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
L. higginsi	0.0000	0.0000	0.0000	0.0000	0.1667	0.0000	0.1667	0.0000	0.0833
T. parvus	0.0000	0.0000	0.0000	0.0000	0.0000	0.1667	0.0000	0.0000	0.0000
F. ebena	0.1667	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C. monodonta	0.0000	0.0833	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0000	0.0000	0.0000	0.0000	0.0833	0.0000	0.0000	0.0000
Total samples	6	12	12	12	12	12	12	11	12

Species	Pool 13						
	554.3L	554.0L	554.0L	554.1L	554.1L	540.8L	540.6L
A. plicata	1.0000	0.9167	1.0000	0.6667	0.8333	0.7500	0.3333
T. truncata	0.5833	1.0000	0.6667	0.8333	0.6667	0.8333	0.5000
O. reflexa	0.8333	0.8333	0.3333	0.3333	0.5833	1.0000	0.6667
O. olivaria	0.7500	0.2500	1.0000	1.0000	0.8333	0.8333	1.0000
M. gigantea	0.2500	0.0833	0.0000	0.0000	0.5000	0.2500	0.0000
E. lineolata	0.0833	0.0833	0.4167	0.1667	0.6667	0.4167	0.0000
Q. quadrula	0.7500	0.1667	0.5000	0.5000	0.2500	0.9167	0.5000
L. ventricosa	0.0833	0.2500	0.2500	0.5000	0.5000	0.3333	0.5000
Q. pustulosa	0.5000	0.3333	0.0000	0.5000	0.1667	0.5000	0.0000
F. flava	0.7500	0.7500	0.5833	0.6667	0.7500	0.5833	0.1667
P. alatus	0.0000	0.1667	0.0000	0.0833	0.1667	0.5000	0.0000
L. recta	0.0833	0.1667	0.0000	0.1667	0.6667	0.1667	0.0000
L. fragilis	0.0000	0.0000	0.0833	0.0833	0.0000	0.1667	0.0000
A. confragosus	0.0833	0.0833	0.1667	0.0000	0.7500	0.0833	0.0000
Q. metanevra	0.0000	0.0000	0.6667	0.5833	0.5000	0.0000	0.0000
A. grandis	0.0833	0.0833	0.0000	0.0000	0.1667	0.0833	0.0000
Q. nodulata	0.0833	0.0000	0.0000	0.1667	0.1667	0.1667	0.0000
S. undulatus	0.0000	0.0000	0.0833	0.0000	0.0833	0.0833	0.0000
T. donaciformis	0.0000	0.0833	0.0000	0.0000	0.0000	0.0833	0.1667
L. complanata	0.0833	0.0000	0.0000	0.0833	0.0000	0.1667	0.0000
A. ligamentina	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
L. higginsi	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T. parvus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F. ebena	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C. monodonta	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total samples	12	12	12	12	12	12	6

(Continued)

* f_i equals the number of samples in which at least one individual of that species was collected divided by the total number of samples.

Table B2 (Concluded)

Species	Pool 12								Pool 10	
	581.0L	581.0L	581.0L	580.9L	581.1L	571.4R	570.0R	570.0R	634.7R	634.7R
A. plicata	0.8333	0.9167	1.0000	0.9167	0.9167	0.4444	0.9167	0.9167	1.0000	1.0000
I. truncata	0.9167	0.9167	0.7500	0.8333	0.8333	0.2222	0.8333	0.1667	0.3333	0.0000
O. reflexa	0.4167	0.3333	0.2500	0.0000	0.5000	0.3333	0.1667	0.0833	0.0000	0.0000
O. olivaria	0.1667	0.2500	0.2500	0.1667	0.0833	0.4444	0.3333	0.2500	0.3333	0.0000
M. gigantea	0.8333	0.8333	0.7500	0.7500	0.5000	0.2222	0.7500	0.8333	0.0000	0.6364
E. lineolata	0.8333	0.5000	0.5833	0.5000	0.5833	0.0000	0.1667	0.0833	0.0000	0.0000
Q. quadrula	0.5833	0.5000	0.3333	0.3333	0.3333	0.0000	0.7500	0.8333	0.0000	0.2727
L. ventricosa	0.7500	0.5000	0.7500	0.7500	0.8333	0.6667	0.6667	0.4167	0.6667	0.2727
Q. pustulosa	0.4167	0.2500	0.3333	0.2500	0.3333	0.2222	0.1667	0.0000	0.3333	0.0909
F. flava	0.6667	0.6667	0.3333	0.2500	0.6667	0.4444	0.3333	0.3333	1.0000	0.2727
P. alatus	0.1667	0.2500	0.5000	0.7500	0.4167	0.5556	0.2500	0.3333	0.6667	0.2727
L. recta	0.2500	0.2500	0.1667	0.2500	0.4167	0.6667	0.4167	0.4167	0.0000	0.0000
L. fragilis	0.2500	0.0000	0.2500	0.4167	0.0833	0.0000	0.0000	0.0000	0.6667	0.0000
A. confragosus	0.1667	0.1667	0.2500	0.4167	0.0000	0.2222	0.5000	0.4167	0.0000	0.0909
O. metanevra	0.0833	0.0833	0.0833	0.0000	0.0000	0.0000	0.0833	0.0000	0.0000	0.0000
A. grandis	0.0000	0.0000	0.1667	0.1667	0.0000	0.3333	0.5833	0.1667	0.0000	0.0000
Q. nodulata	0.0000	0.0000	0.0000	0.0000	0.0833	0.0000	0.0000	0.0833	0.0000	0.0000
S. undulatus	0.0833	0.0833	0.4167	0.0000	0.0000	0.0000	0.1667	0.0833	0.0000	0.0000
T. donaciformis	0.0833	0.0000	0.1667	0.1667	0.0833	0.0000	0.0000	0.1667	0.0000	0.0000
L. complanata	0.0833	0.0000	0.0833	0.0833	0.0000	0.1111	0.0000	0.0833	0.0000	0.0909
A. ligamentina	0.1667	0.1667	0.0833	0.0000	0.0000	0.3333	0.0833	0.0000	0.0000	0.0000
L. higginsi	0.0000	0.0000	0.0000	0.0000	0.1667	0.0000	0.0833	0.0000	0.0000	0.0000
T. parvus	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F. ebena	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C. monodonta	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total samples	12	12	12	12	12	12	9	12	3	11

Table B3

Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Qualitative Techniques in the Upper Mississippi River, July and September, 1989*

	Relative Species Abundance					Frequency of Ocurrence				
	Pool					Pool				
	24	14	13	12	10	24	14	13	12	10
A. plicata	0.1327	0.3788	0.2224	0.2118	0.7877	0.7857	0.9661	0.8833	0.9167	1.0000
T. truncata	0.0849	0.0583	0.1592	0.2062	0.0047	0.5714	0.4746	0.7500	0.8500	0.0714
Q. reflexa	0.0710	0.2237	0.0853	0.0212	0.0000	0.5238	0.7627	0.5833	0.3000	0.0000
Q. olivaria	0.0525	0.0094	0.2349	0.0123	0.0047	0.5714	0.1525	0.7667	0.1833	0.0714
M. gigantea	0.1497	0.0187	0.0125	0.0959	0.0566	0.8095	0.2542	0.1667	0.7333	0.5000
E. lineolata	0.2269	0.0083	0.0268	0.0792	0.0000	0.9048	0.1356	0.2833	0.6000	0.0000
Q. quadrula	0.0432	0.0801	0.0336	0.0390	0.0142	0.4048	0.6102	0.4333	0.4167	0.2143
L. ventricosa	0.0293	0.0198	0.0345	0.1171	0.0283	0.3571	0.1864	0.3167	0.7167	0.3571
Q. pustulosa	0.0417	0.1249	0.0230	0.0379	0.0094	0.4762	0.7119	0.3000	0.3167	0.1429
F. flava	0.0201	0.0239	0.0834	0.0524	0.0377	0.2381	0.3051	0.7000	0.5167	0.4286
P. alatus	0.0293	0.0104	0.0058	0.0412	0.0377	0.3571	0.1525	0.0833	0.4167	0.3571
L. recta	0.0093	0.0031	0.0134	0.0268	0.0000	0.1190	0.0399	0.2167	0.2667	0.0000
L. fragilis	0.0787	0.0042	0.0019	0.0145	0.0094	0.5952	0.0678	0.0333	0.2000	0.1429
A. confragosus	0.0015	0.0073	0.0192	0.0089	0.0047	0.0714	0.0678	0.2167	0.2000	0.0714
Q. metanevra	0.0154	0.0010	0.0307	0.0033	0.0000	0.2381	0.0169	0.3500	0.0500	0.0000
A. grandis	0.0031	0.0104	0.0038	0.0056	0.0000	0.0476	0.1186	0.0667	0.0667	0.0000
Q. nodulata	0.0046	0.0083	0.0048	0.0011	0.0000	0.0714	0.1356	0.0833	0.0167	0.0000
S. undulatus	0.0000	0.0000	0.0019	0.0078	0.0000	0.0000	0.0000	0.0333	0.1167	0.0000
T. donaciformis	0.0031	0.0000	0.0010	0.0067	0.0000	0.0476	0.0000	0.0167	0.1000	0.0000
L. complanata	0.0000	0.0010	0.0019	0.0033	0.0047	0.0000	0.0169	0.0333	0.0500	0.0714
A. ligamentina	0.0000	0.0000	0.0000	0.0056	0.0000	0.0000	0.0000	0.0000	0.0833	0.0000
L. higginsi	0.0000	0.0052	0.0000	0.0022	0.0000	0.0000	0.0847	0.0000	0.0333	0.0000
T. parvus	0.0000	0.0021	0.0000	0.0000	0.0000	0.0000	0.0339	0.0000	0.0000	0.0000
F. ebena	0.0015	0.0000	0.0000	0.0000	0.0000	0.0238	0.0000	0.0000	0.0000	0.0000
P. laevissima	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0169	0.0000	0.0000	0.0000
C. monodonta	0.0015	0.0000	0.0000	0.0000	0.0000	0.0238	0.0000	0.0000	0.0000	0.0000
Total individuals	648	961	1296	1355	212					
Total samples						42	59	78	93	14

* f_i equals the number of samples in which at least one individual of that species was collected divided by the total number of samples.

APPENDIX C

FRESHWATER BIVALVES COLLECTED IN THE UPPER MISSISSIPPI RIVER IN 1989 USING QUANTITATIVE TECHNIQUES

Table C1

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 299.4, Pool 24 of the UMR*

Species	Nearshore p_i	Nearshore f_i	Farshore p_i	Farshore f_i
T. truncata	0.2645	0.6000	0.2895	1.0000
E. lineolata	0.2029	0.7667	0.1396	0.9333
T. donaciformis	0.1449	0.5667	0.1476	0.9667
A. plicata	0.1304	0.5667	0.0980	0.9000
O. reflexa	0.1232	0.5000	0.1153	0.8333
L. fragilis	0.0435	0.3333	0.0704	0.7667
C. fluminea	0.0217	0.1333	0.0196	0.4000
O. olivaria	0.0190	0.1000	0.0104	0.3000
M. gigantea	0.0181	0.1667	0.0473	0.7333
Q. pustulosa	0.0145	0.1333	0.0127	0.2667
Q. nodulata	0.0109	0.1000	--	--
F. flava	0.0036	0.0333	0.0035	0.0667
L. complanata	0.0036	0.0333	0.0046	0.1000
L. ventricosa	0.0036	0.0333	0.0058	0.1667
Q. quadrula	0.0036	0.0333	0.0161	0.3667
A. imbecillis	--	--	0.0012	0.0333
L. recta	--	--	0.0012	0.0333
P. alata	--	--	0.0058	0.1667
Q. metanevra	--	--	0.0115	0.2667

	Nearshore	Farshore
Total individuals	276	867
Total species	15	18
Total samples	30	30
Diversity (H')	2.01	2.141
Evenness (J)	0.74	0.741
Total individuals < 30 mm total SL	53.6%	64.1%
Total species < 30 mm total SL	11	12

* Nearshore = 100 ft from RDB, farshore = 200 ft from RDB.

Table C2

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 504.6, Pool 14 of the UMR (Downriver Site)

Species	p_i	f_i
A. plicata	0.2436	1.0000
T. truncata	0.2179	0.8000
Q. pustulosa	0.1538	1.0000
O. reflexa	0.1410	0.6000
O. olivaria	0.0513	0.4000
E. lineolata	0.0385	0.4000
Q. quadrula	0.0385	0.2000
Q. nodulata	0.0385	0.4000
M. gigantea	0.0256	0.4000
F. flava	0.0128	0.2000
P. laevissima	0.0128	0.2000
Q. metanevra	0.0128	0.2000
T. donaciformis	0.0128	0.2000

Total individuals	78
Total species	13
Total samples	5
Diversity (H')	2.084
Evenness (J)	0.813
Total individuals < 30 mm total SL	33.3%
Total species < 30 mm total SL	6

Table C3

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 505.2, Pool 14 of the UMR (Upriver Site)

Species	p_i	f_i
T. truncata	0.3548	1.0000
F. flava	0.1290	0.6000
A. plicata	0.1129	0.8000
Q. pustulosa	0.1129	0.8000
Q. quadrula	0.0806	0.6000
M. gigantea	0.0806	0.6000
O. reflexa	0.0645	0.6000
O. olivaria	0.0484	0.6000
E. lineolata	0.0161	0.2000

Total individuals	62
Total species	9
Total samples	5
Diversity (H')	1.92
Evenness (J)	0.84
Total individuals < 30 mm total SL	40.3%
Total species < 30 mm total SL	5

Table C4

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 504.8, Pool 14 of the UMR (100 ft from RDB)

Species	p_i	f_i
T. truncata	0.2639	1.0000
O. reflexa	0.1806	1.0000
A. plicata	0.1667	0.8000
Q. pustulosa	0.1250	1.0000
F. flava	0.0694	0.6000
L. ventricosa	0.0278	0.2000
E. lineolata	0.0417	0.4000
Q. quadrula	0.0417	0.4000
M. gigantea	0.0278	0.4000
P. alata	0.0278	0.4000
L. fragilis	0.0139	0.2000
O. olivaria	0.0139	0.2000

Total individuals	72
Total species	12
Total samples	5
Diversity (H')	2.086
Evenness (J)	0.840
Total individuals < 30 mm total SL	31.9%
Total species < 30 mm total SL	8

Table C5

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 504.8, Pool 14 of the UMR*

Species	Nearshore p_i	Nearshore f_i	Farshore p_i	Farshore f_i
T. truncata	0.2135	0.9667	0.2832	0.7667
Q. pustulosa	0.1923	0.8667	0.1253	0.7333
A. plicata	0.1385	0.8667	0.1003	0.6333
O. reflexa	0.1365	0.9333	0.0727	0.6000
Q. quadrula	0.0846	0.8667	0.0777	0.5000
O. olivaria	0.0462	0.5333	0.1078	0.7000
E. lineolata	0.0327	0.4667	0.0326	0.3667
F. flava	0.0288	0.3667	0.0401	0.3667
L. fragilis	0.0288	0.2667	0.0476	0.4333
M. gigantea	0.0269	0.4667	0.0251	0.3000
L. ventricosa	0.0173	0.2333	0.0226	0.3000
P. alata	0.0135	0.2000	0.0276	0.2667
T. donaciformis	0.0135	0.2000	0.0075	0.1000
L. complanata	0.0077	0.1333	0.0050	0.0667
A. confragosus	0.0058	0.1000	0.0050	0.0667
L. recta	0.0038	0.0667	--	--
Q. metanevra	0.0038	0.0667	0.0025	0.0333
Q. nodulata	0.0038	0.0667	0.0025	0.0333
A. grandis	0.0019	0.0333	--	--
E. dilatata	--	--	0.0025	0.0333
L. higginsi	--	--	0.0025	0.0333
L. costata	--	--	0.0025	0.0333
P. laevissima	--	--	0.0075	0.1000

	Nearshore	Farshore
Total individuals	520	399
Total species	19	21
Total samples	30	30
Diversity (H')	2.286	2.339
Evenness (J)	0.777	0.769
Total individuals < 30 mm total SL	27.7%	22.3%
Total species < 30 mm total SL	10	11

* Main site (nearshore) located 160 ft from bank, farshore site located 300 ft from bank.

Table C6

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 635.7, Pool 10 of the UMR*

Species	p_i	f_i
A. plicata	0.7860	1.0000
F. flava	0.0453	0.4500
M. gigantea	0.0412	0.3000
T. truncata	0.0288	0.3000
Q. quadrula	0.0206	0.2000
Q. pustulosa	0.0165	0.2000
L. higginsi	0.0123	0.1500
P. reflexa	0.0123	0.1000
A. imbecillis	0.0082	0.1000
T. donaciformis	0.0082	0.1000
C. parvus	0.0082	0.1000
L. complanata	0.0041	0.0500
P. alatus	0.0041	0.0500
Q. nodulata	0.0041	0.0500

Total individuals	243
Total species	14
Total samples	20
Diversity (H')	1.004
Evenness (J)	0.38
Total individuals < 30 mm total SL	20.6%
Total species < 30 mm total SL	7

* Samples were collected in the turning basin in the north portion of the east channel (500 ft from LDB).

Table C7

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 635.4, Pool 10 of the UMR*

Species	p_i	f_i
A. plicata	0.5263	1.0000
F. flava	0.0957	0.8000
T. truncata	0.0718	0.7000
M. gigantea	0.0574	0.6000
Q. quadrula	0.0478	0.5000
Q. pustulosa	0.0383	0.3000
O. reflexa	0.0335	0.6000
L. recta	0.0239	0.5000
L. higginsi	0.0144	0.3000
L. ventricosa	0.0144	0.1000
T. donaciformis	0.0144	0.2000
Q. nodulata	0.0144	0.3000
A. confragosus	0.0096	0.2000
A. imbecillis	0.0096	0.2000
L. fragilis	0.0096	0.2000
E. dilatata	0.0096	0.1000
O. olivaria	0.0048	0.1000
P. alatus	0.0048	0.1000

Total individuals	209
Total species	18
Total samples	10
Diversity (H')	1.861
Evenness (J)	0.664
Total individuals < 30 mm total SL	20.6%
Total species < 30 mm total SL	7

* Samples were collected downriver of the turning basin in the north portion of the east channel 200 ft from LDB.

Table C8

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 634.7, Pool 10 of the UMR*

Species	p_i	f_i
A. plicata	0.7103	0.9500
F. flava	0.0379	0.4500
T. truncata	0.0379	0.3500
Q. quadrula	0.0345	0.4000
L. ventricosa	0.0276	0.3000
A. confragosus	0.0241	0.2500
O. reflexa	0.0207	0.3000
M. gigantea	0.0172	0.2500
Q. pustulosa	0.0172	0.2000
O. olivaria	0.0172	0.2000
L. fragilis	0.0103	0.1500
Q. nodulata	0.0103	0.1000
L. higginsi	0.0069	0.1000
L. complanata	0.0069	0.1000
P. alatus	0.0069	0.1000
T. donaciformis	0.0069	0.1000
L. recta	0.0034	0.0500
S. undulatus	0.0034	0.0500

Total individuals	290
Total species	18
Total samples	20
Diversity (H')	1.356
Evenness (J)	0.469
Total individuals < 30 mm total SL	10.2%
Total species < 30 mm total SL	9

* Samples were collected in the Wisconsin side of the main channel, 100 ft from LDB.

Table C9

Relative Species Abundance (p_i) and Frequency of Occurrence (f_i) of Mussels Collected Using Quantitative Techniques at RM 634.7, Pool 10 of the UMR*

Species	Nearshore p_i	Nearshore f_i	Farshore p_i	Farshore f_i
A. plicata	0.5759	1.0000	0.6679	1.0000
T. truncata	0.0588	0.6000	0.0799	0.8000
O. reflexa	0.0557	0.5555	0.0236	0.5000
T. donaciformis	0.0495	0.6000	0.0145	0.3000
M. gigantea	0.0402	0.5000	0.0345	0.5000
L. ventricosa	0.0341	0.4000	0.0254	0.5000
Q. quadrula	0.0279	0.4000	0.0363	0.6000
P. alata	0.0248	0.4000	0.0109	0.2000
E. dilatata	0.0248	0.4000	0.0091	0.2000
F. flava	0.0217	0.3500	0.0345	0.6500
L. fragilis	0.0217	0.2500	0.0145	0.3000
A. imbecillis	0.0186	0.2500	0.0109	0.2000
L. recta	0.0124	0.2000	0.0091	0.2000
A. grandis	0.0093	0.1500	--	--
Q. pustulosa	0.0062	0.1000	0.0054	0.1500
A. confragosus	0.0031	0.0050	0.0073	0.1000
L. higginsi	0.0031	0.0500	0.0036	0.0500
O. olivaria	0.0031	0.0500	0.0036	0.1000
Q. nodulata	0.0031	0.0500	0.0054	0.1500
Q. metanevra	--	--	0.0018	0.0500
P. laevissima	--	--	0.0018	0.0500

	Nearshore	Farshore
Total individuals	323	551
Total species	20	20
Total samples	20	20
Diversity (H')	1.794	1.467
Evenness (J)	0.599	0.49
Total individuals < 30 mm total SL	17.0%	16.1%
Total species < 30 mm total SL	8	8

* Nearshore = 115 ft from RDB, farshore = 180 ft from RDB. Samples were collected on the Iowa side of the river.

APPENDIX D

LENGTH-FREQUENCY HISTOGRAMS FOR BIVALVES COLLECTED IN THE UMR, 1988-89

```
Shell Length                                                       Cumulative      Cumulative
                                                            Freq   Freq  Percent   Percent
            |
      0     |                                                  0      0    0.00       0.00
      4     |                                                  0      0    0.00       0.00
      8     |*********                                        21     21   17.36      17.36
     12     |*******************************                  75     96   61.98      79.34
     16     |**                                                6    102    4.96      84.30
     20     |*                                                 2    104    1.65      85.95
     24     |*                                                 2    106    1.65      87.60
     28     |*                                                 3    109    2.48      90.08
     32     |*                                                 3    112    2.48      92.56
     36     |                                                  0    112    0.00      92.56
     40     |                                                  0    112    0.00      92.56
     44     |                                                  1    113    0.83      93.39
     48     |                                                  0    113    0.00      93.39
     52     |                                                  1    114    0.83      94.21
     56     |                                                  0    114    0.00      94.21
     60     |                                                  0    114    0.00      94.21
     64     |                                                  0    114    0.00      94.21
     68     |                                                  0    114    0.00      94.21
     72     |                                                  1    115    0.83      95.04
     76     |                                                  0    115    0.00      95.04
     80     |                                                  0    115    0.00      95.04
     84     |                                                  0    115    0.00      95.04
     88     |                                                  1    116    0.83      95.87
     92     |                                                  0    116    0.00      95.87
     96     |**                                                4    120    3.31      99.17
    100     |                                                  1    121    0.83     100.00
    104     |                                                  0    121    0.00     100.00
            -----+----+----+----+----+----+-
                10   20   30   40   50   60

                     Percentage
```

Figure D1. Shell length (mm) frequency histogram of *Amblema plicata* in the upper Mississippi River, RM 299 (pool 24) nearshore and farshore sites combined, July 1989

```
Shell Length                                                       Cumulative      Cumulative
                                                            Freq   Freq  Percent   Percent
            |
      0     |                                                  0      0    0.00       0.00
      4     |                                                  0      0    0.00       0.00
      8     |                                                  0      0    0.00       0.00
     12     |                                                  0      0    0.00       0.00
     16     |**                                                3      3    1.69       1.69
     20     |*************                                    23     26   12.99      14.69
     24     |*****************************                    52     78   29.38      44.07
     28     |*****                                             8     86    4.52      48.59
     32     |**                                                3     89    1.69      50.28
     36     |****                                              7     96    3.95      54.24
     40     |***                                               6    102    3.39      57.63
     44     |*******                                          12    114    6.78      64.41
     48     |****                                              7    121    3.95      68.36
     52     |**                                                3    124    1.69      70.06
     56     |*                                                 1    125    0.56      70.62
     60     |*                                                 2    127    1.13      71.75
     64     |*****                                             9    136    5.08      76.84
     68     |****                                              7    143    3.95      80.79
     72     |**                                                4    147    2.26      83.05
     76     |*****                                             8    155    4.52      87.57
     80     |***                                               5    160    2.82      90.40
     84     |**                                                4    164    2.26      92.66
     88     |***                                               6    170    3.39      96.05
     92     |****                                              7    177    3.95     100.00
     96     |                                                  0    177    0.00     100.00
    100     |                                                  0    177    0.00     100.00
    104     |                                                  0    177    0.00     100.00
            -----+----+----+----+----+----
                 5   10   15   20   25

                     Percentage
```

Figure D2. Shell length (mm) frequency histogram of *Ellipsaria lineolata* in the upper Mississippi River, RM 299 (pool 24) nearshore and farshore sites combined, July 1989

```
Shell Length
                                                  Cumulative    Cumulative
                                          Freq   Freq  Percent   Percent
     |
   0 |                                       0      0     0.00      0.00
   4 |                                       0      0     0.00      0.00
   8 |                                       0      0     0.00      0.00
  12 |                                       0      0     0.00      0.00
  16 |*******                                2      2     3.57      3.57
  20 |**************                         4      6     7.14     10.71
  24 |******************                     5     11     8.93     19.64
  28 |*******                                2     13     3.57     23.21
  32 |*******                                2     15     3.57     26.79
  36 |*************************              7     22    12.50     39.29
  40 |******************                     5     27     8.93     48.21
  44 |************************************  10     37    17.86     66.07
  48 |**************                         4     41     7.14     73.21
  52 |*******                                2     43     3.57     76.79
  56 |                                       0     43     0.00     76.79
  60 |****                                   1     44     1.79     78.57
  64 |***********                            3     47     5.36     83.93
  68 |****                                   1     48     1.79     85.71
  72 |*******                                2     50     3.57     89.29
  76 |                                       0     50     0.00     89.29
  80 |*******                                2     52     3.57     92.86
  84 |****                                   1     53     1.79     94.64
  88 |****                                   1     54     1.79     96.43
  92 |*******                                2     56     3.57    100.00
  96 |                                       0     56     0.00    100.00
 100 |                                       0     56     0.00    100.00
 104 |                                       0     56     0.00    100.00
     ----+---+---+---+---+---+---+---+---+
         2   4   6   8  10  12  14  16  18

              Percentage
```

Figure D3. Shell length (mm) frequency histogram of *Ellipsaria lineolata* in the upper Mississippi River, RM 299 (pool 24) nearshore site, July 1989

```
Shell Length
                                                    Cumulative    Cumulative
                                            Freq   Freq  Percent   Percent
     |
   0 |                                         0      0     0.00      0.00
   4 |                                         0      0     0.00      0.00
   8 |                                         0      0     0.00      0.00
  12 |                                         0      0     0.00      0.00
  16 |*                                        1      1     0.83      0.83
  20 |****************                        19     20    15.70     16.53
  24 |***************************************  47     67    38.84     55.37
  28 |*****                                    6     73     4.96     60.33
  32 |*                                        1     74     0.83     61.16
  36 |                                         0     74     0.00     61.16
  40 |*                                        1     75     0.83     61.98
  44 |**                                       2     77     1.65     63.64
  48 |**                                       3     80     2.48     66.12
  52 |*                                        1     81     0.83     66.94
  56 |*                                        1     82     0.83     67.77
  60 |*                                        1     83     0.83     68.60
  64 |*****                                    6     89     4.96     73.55
  68 |*****                                    6     95     4.96     78.51
  72 |**                                       2     97     1.65     80.17
  76 |*******                                  8    105     6.61     86.78
  80 |**                                       3    108     2.48     89.26
  84 |**                                       3    111     2.48     91.74
  88 |****                                     5    116     4.13     95.87
  92 |****                                     5    121     4.13    100.00
  96 |                                         0    121     0.00    100.00
 100 |                                         0    121     0.00    100.00
 104 |                                         0    121     0.00    100.00
     -----+----+----+----+----+----+----+----
          5   10   15   20   25   30   35

              Percentage
```

Figure D4. Shell length (mm) frequency histogram of *Ellipsaria lineolata* in the upper Mississippi River RM 299 (pool 24) farshore site, July 1989

```
Shell Length                                      Cumulative    Cumulative
                                         Freq   Freq  Percent   Percent
                |
    0           |                          0      0     0.00      0.00
    4           |                          0      0     0.00      0.00
    8           |                          0      0     0.00      0.00
   12           |                          0      0     0.00      0.00
   16           |***                       1      1     1.37      1.37
   20           |                          0      1     0.00      1.37
   24           |                          0      1     0.00      1.37
   28           |                          0      1     0.00      1.37
   32           |***                       1      2     1.37      2.74
   36           |                          0      2     0.00      2.74
   40           |***********               4      6     5.48      8.22
   44           |***********               4     10     5.48     13.70
   48           |*******************       7     17     9.59     23.29
   52           |*******************       7     24     9.59     32.88
   56           |**********************    8     32    10.96     43.84
   60           |****************          6     38     8.22     52.05
   64           |*************************** 10  48    13.70     65.75
   68           |********                  3     51     4.11     69.86
   72           |***********               4     55     5.48     75.34
   76           |                          0     55     0.00     75.34
   80           |********                  3     58     4.11     79.45
   84           |**************            5     63     6.85     86.30
   88           |********                  3     66     4.11     90.41
   92           |********                  3     69     4.11     94.52
   96           |***                       1     70     1.37     95.89
  100           |*****                     2     72     2.74     98.63
  104           |                          0     72     0.00     98.63
  108           |                          0     72     0.00     98.63
  112           |                          0     72     0.00     98.63
  116           |***                       1     73     1.37    100.00
  120           |                          0     73     0.00    100.00
  124           |                          0     73     0.00    100.00
                ----+---+---+---+---+---+---
                    2   4   6   8   10  12

                          Percentage
```

Figure D5. Shell length (mm) frequency histogram of *Leptodea fragilis* in the upper Mississippi River, RM 299 (pool 24) nearshore and farshore sites combined, July 1989

```
Shell Length                                              Cumulative    Cumulative
                                                 Freq   Freq  Percent   Percent
    0       |                                      0      0     0.00      0.00
    4       |                                      0      0     0.00      0.00
    8       |                                      0      0     0.00      0.00
   12       |*************                         9      9     6.72      6.72
   16       |**********************************   23     32    17.16     23.88
   20       |****                                  3     35     2.24     26.12
   24       |****************                     11     46     8.21     34.33
   28       |****************************         19     65    14.18     48.51
   32       |************                          8     73     5.97     54.48
   36       |****************                     11     84     8.21     62.69
   40       |******************                   12     96     8.96     71.64
   44       |*******************                  13    109     9.70     81.34
   48       |******                                4    113     2.99     84.33
   52       |**********                            7    120     5.22     89.55
   56       |*********                             6    126     4.48     94.03
   60       |*********                             6    132     4.48     98.51
   64       |*                                     1    133     0.75     99.25
   68       |*                                     1    134     0.75    100.00
   72       |                                      0    134     0.00    100.00
   76       |                                      0    134     0.00    100.00
   80       |                                      0    134     0.00    100.00
            ----+---+---+---+---+---+---+---+--
                2   4   6   8   10  12  14  16

                         Percentage
```

Figure D6. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 299 (pool 24) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
4		0	0	0.00	0.00
8		0	0	0.00	0.00
12	***	1	1	2.94	2.94
16	*********	3	4	8.82	11.76
20		0	4	0.00	11.76
24	*********	3	7	8.82	20.59
28	*********************	7	14	20.59	41.18
32	***************	5	19	14.71	55.88
36	***************	5	24	14.71	70.59
40	************	4	28	11.76	82.35
44	************	4	32	11.76	94.12
48		0	32	0.00	94.12
52	***	1	33	2.94	97.06
56		0	33	0.00	97.06
60		0	33	0.00	97.06
64		0	33	0.00	97.06
68	***	1	34	2.94	100.00
72		0	34	0.00	100.00
76		0	34	0.00	100.00
80		0	34	0.00	100.00
84		0	34	0.00	100.00
	-----+----+----+----+- 5 10 15 20				

Percentage

Figure D7. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 299 (pool 24) nearshore site, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
4		0	0	0.00	0.00
8		0	0	0.00	0.00
12	********	8	8	8.00	8.00
16	********************	20	28	20.00	28.00
20	***	3	31	3.00	31.00
24	********	8	39	8.00	39.00
28	************	12	51	12.00	51.00
32	***	3	54	3.00	54.00
36	******	6	60	6.00	60.00
40	********	8	68	8.00	68.00
44	*********	9	77	9.00	77.00
48	****	4	81	4.00	81.00
52	******	6	87	6.00	87.00
56	******	6	93	6.00	93.00
60	******	6	99	6.00	99.00
64	*	1	100	1.00	100.00
68		0	100	0.00	100.00
72		0	100	0.00	100.00
76		0	100	0.00	100.00
	----+----+----+----+ 5 10 15 20				

Percentage

Figure D8. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 299 (pool 24) nearshore site, July 1989

```
Shell Length                                          Cumulative       Cumulative
                                                Freq  Freq   Percent   Percent
          |
   0      |                                      0      0     0.00       0.00
   4      |                                      0      0     0.00       0.00
   8      |                                      0      0     0.00       0.00
  12      |*******************                  64     64    38.10      38.10
  16      |**************************           86    150    51.19      89.29
  20      |***                                  11    161     6.55      95.83
  24      |*                                     2    163     1.19      97.02
  28      |*                                     3    166     1.79      98.81
  32      |                                      0    166     0.00      98.81
  36      |                                      1    167     0.60      99.40
  40      |                                      0    167     0.00      99.40
  44      |                                      1    168     0.60     100.00
  48      |                                      0    168     0.00     100.00
          -----+----+----+----+----+-
              10   20   30   40   50

                 Percentage
```

Figure D9. Shell length (mm) frequency histogram of *Truncilla donaciformis* in the upper Mississippi River, RM 299 (pool 24) nearshore and farshore sites combined, July 1989

```
Shell Length                                       Cumulative       Cumulative
                                             Freq  Freq   Percent   Percent
          |
   0      |                                    0      0     0.00       0.00
   4      |                                    0      0     0.00       0.00
   8      |                                    0      0     0.00       0.00
  12      |***                                21     21     6.48       6.48
  16      |**********************            141    162    43.52      50.00
  20      |******                             38    200    11.73      61.73
  24      |**                                 11    211     3.40      65.12
  28      |****                               25    236     7.72      72.84
  32      |*****                              30    266     9.26      82.10
  36      |**                                 15    281     4.63      86.73
  40      |***                                18    299     5.56      92.28
  44      |***                                20    319     6.17      98.46
  48      |                                    3    322     0.93      99.38
  52      |                                    2    324     0.62     100.00
  56      |                                    0    324     0.00     100.00
          -----+----+----+----+--
              10   20   30   40

                 Percentage
```

Figure D10. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 299 (pool 24) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
10		0	0	0.00	0.00
12	**	6	6	2.39	2.39
14	***********	28	34	11.16	13.55
16	******************************	75	109	29.88	43.43
18	************************	59	168	23.51	66.93
20	******	15	183	5.98	72.91
22		0	183	0.00	72.91
24		1	184	0.40	73.31
26	**	6	190	2.39	75.70
28	**	4	194	1.59	77.29
30	*****	12	206	4.78	82.07
32	**	4	210	1.59	83.67
34	**	5	215	1.99	85.66
36		1	216	0.40	86.06
38	**	4	220	1.59	87.65
40	***	8	228	3.19	90.84
42	**	6	234	2.39	93.23
44	****	9	243	3.59	96.81
46	**	4	247	1.59	98.41
48		0	247	0.00	98.41
50	*	3	250	1.20	99.60
52		1	251	0.40	100.00
54		0	251	0.00	100.00
	5 10 15 20 25 30				

Percentage

Figure D11. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 299.6 (pool 24), (pool 24), nearshore site, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10		0	0	0.00	0.00
12	*****	2	2	2.74	2.74
14	****************	6	8	8.22	10.96
16	**************	5	13	6.85	17.81
18	***	1	14	1.37	19.18
20	********	3	17	4.11	23.29
22	***	1	18	1.37	24.66
24	**************	5	23	6.85	31.51
26	**********************	8	31	10.96	42.47
28	**************	5	36	6.85	49.32
30	****************	6	42	8.22	57.53
32	*************************	9	51	12.33	69.86
34	********	3	54	4.11	73.97
36	***********	4	58	5.48	79.45
38	**********************	8	66	10.96	90.41
40	***********	4	70	5.48	95.89
42	*****	2	72	2.74	98.63
44	***	1	73	1.37	100.00
46		0	73	0.00	100.00
48		0	73	0.00	100.00
50		0	73	0.00	100.00
	2 4 6 8 10 12				

Percentage

Figure D12. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 299.6 (pool 24) farshore site, July 1989

```
Shell Length                                     Cumulative          Cumulative
                                            Freq   Freq    Percent    Percent
      |
   0  |                                        0      0      0.00       0.00
   4  |                                        0      0      0.00       0.00
   8  |                                        0      0      0.00       0.00
  12  |                                        0      0      0.00       0.00
  16  |*************                           7      7      6.25       6.25
  20  |*************************              14     21     12.50      18.75
  24  |**                                      1     22      0.89      19.64
  28  |                                        0     22      0.00      19.64
  32  |****                                    2     24      1.79      21.43
  36  |****                                    2     26      1.79      23.21
  40  |****                                    2     28      1.79      25.00
  44  |                                        0     28      0.00      25.00
  48  |**                                      1     29      0.89      25.89
  52  |****                                    2     31      1.79      27.68
  56  |****                                    2     33      1.79      29.46
  60  |***********                             6     39      5.36      34.82
  64  |**************                          8     47      7.14      41.96
  68  |***********                             6     53      5.36      47.32
  72  |******************                     10     63      8.93      56.25
  76  |*******                                 4     67      3.57      59.82
  80  |********************                   11     78      9.82      69.64
  84  |*********                               5     83      4.46      74.11
  88  |*********************                  12     95     10.71      84.82
  92  |******************                     10    105      8.93      93.75
  96  |*****                                   3    108      2.68      96.43
 100  |**                                      1    109      0.89      97.32
 104  |****                                    2    111      1.79      99.11
 108  |                                        0    111      0.00      99.11
 112  |**                                      1    112      0.89     100.00
 116  |                                        0    112      0.00     100.00
 120  |                                        0    112      0.00     100.00
      ----+---+---+---+---+---+-
          2   4   6   8  10  12

             Percentage
```

Figure D13. Shell length (mm) frequency histogram *Amblema plicata* in the upper Mississippi River, RM 505 (pool 14) nearshore and farshore sites combined, July 1989

```
Shell Length                                             Cumulative          Cumulative
                                                    Freq   Freq    Percent    Percent
     |
  0  |                                                 0      0      0.00       0.00
  4  |                                                 0      0      0.00       0.00
  8  |                                                 0      0      0.00       0.00
 12  |                                                 0      0      0.00       0.00
 16  |**                                               2      2      2.00       2.00
 20  |***                                              3      5      3.00       5.00
 24  |***                                              3      8      3.00       8.00
 28  |****                                             4     12      4.00      12.00
 32  |****************                                16     28     16.00      28.00
 36  |***************                                 15     43     15.00      43.00
 40  |************************************            36     79     36.00      79.00
 44  |**********                                      10     89     10.00      89.00
 48  |*******                                          7     96      7.00      96.00
 52  |                                                 0     96      0.00      96.00
 56  |****                                             4    100      4.00     100.00
 60  |                                                 0    100      0.00     100.00
     -----+----+----+----+----+----+----+-
          5   10   15   20   25   30   35

                 Percentage
```

Figure D14. Shell length (mm) frequency histogram of *Obliquaria reflexa* in the upper Mississippi River, RM 505 (pool 14) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
2		0	0	0.00	0.00
4		0	0	0.00	0.00
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10		0	0	0.00	0.00
12		0	0	0.00	0.00
14		0	0	0.00	0.00
16		0	0	0.00	0.00
18	*****	1	1	2.33	2.33
20		0	1	0.00	2.33
22		0	1	0.00	2.33
24		0	1	0.00	2.33
26		0	1	0.00	2.33
28		0	1	0.00	2.33
30		0	1	0.00	2.33
32		0	1	0.00	2.33
34		0	1	0.00	2.33
36		0	1	0.00	2.33
38	**********	2	3	4.65	6.98
40		0	3	0.00	6.98
42	***************	3	6	6.98	13.95
44	***************	3	9	6.98	20.93
46	******************************	6	15	13.95	34.88
48	*************************	5	20	11.63	46.51
50	******************************	6	26	13.95	60.47
52	********************	4	30	9.30	69.77
54	***************	3	33	6.98	76.74
56		0	33	0.00	76.74
58	**********	2	35	4.65	81.40
60	*****	1	36	2.33	83.72
62		0	36	0.00	83.72
64	********************	4	40	9.30	93.02
66	*****	1	41	2.33	95.35
68		0	41	0.00	95.35
70	*****	1	42	2.33	97.67
72	*****	1	43	2.33	100.00
74		0	43	0.00	100.00
76		0	43	0.00	100.00

2 4 6 8 10 12 14

Percentage

Figure D15. Shell length (mm) frequency histogram of *Obovaria olivaria* in the upper Mississippi River, RM 505 (pool 14) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
2		0	0	0.00	0.00
4		0	0	0.00	0.00
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10		0	0	0.00	0.00
12		0	0	0.00	0.00
14	************	4	4	2.67	2.67
16	*********	3	7	2.00	4.67
18	*********	3	10	2.00	6.67
20	************************	8	18	5.33	12.00
22	******************	6	24	4.00	16.00
24	******************	6	30	4.00	20.00
26	******************	6	36	4.00	24.00
28	*********************	7	43	4.67	28.67
30	*********************	7	50	4.67	33.33
32	******************	6	56	4.00	37.33
34	************	4	60	2.67	40.00
36	************************************	12	72	8.00	48.00
38	*********************	7	79	4.67	52.67
40	***************	5	84	3.33	56.00
42	***************	5	89	3.33	59.33
44	*********************	7	96	4.67	64.00
46	***************************	9	105	6.00	70.00
48	***************************************	13	118	8.67	78.67
50	***************************************	13	131	8.67	87.33
52	******************	6	137	4.00	91.33
54	******	2	139	1.33	92.67
56	******	2	141	1.33	94.00
58	***************	5	146	3.33	97.33
60	******	2	148	1.33	98.67
62	***	1	149	0.67	99.33
64	***	1	150	0.67	100.00
66		0	150	0.00	100.00
68		0	150	0.00	100.00

1 2 3 4 5 6 7 8

Percentage

Figure D16. Shell length (mm) frequency histogram of *Quadrula pustulosa* in the upper Mississippi River, RM 505 (pool 14) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
4		0	0	0.00	0.00
8		0	0	0.00	0.00
12		0	0	0.00	0.00
16	********	3	3	4.00	4.00
20	********	3	6	4.00	8.00
24	***********	4	10	5.33	13.33
28		0	10	0.00	13.33
32	*****	2	12	2.67	16.00
36	****************	6	18	8.00	24.00
40	***	1	19	1.33	25.33
44	********	3	22	4.00	29.33
48	********	3	25	4.00	33.33
52	*****	2	27	2.67	36.00
56	*******************	7	34	9.33	45.33
60	*******************	7	41	9.33	54.67
64	***********	4	45	5.33	60.00
68	****************	6	51	8.00	68.00
72	********************************	12	63	16.00	84.00
76	********	3	66	4.00	88.00
80	*******************	7	73	9.33	97.33
84	*****	2	75	2.67	100.00
88		0	75	0.00	100.00
92		0	75	0.00	100.00
96		0	75	0.00	100.00

2 4 6 8 10 12 14 16

Percentage

Figure D17. Shell length (mm) frequency histogram of *Quadrula quadrula* in the upper Mississippi River, RM 505 (pool 14) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
2		0	0	0.00	0.00
4		0	0	0.00	0.00
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10	*	1	1	0.45	0.45
12		0	1	0.00	0.45
14	*	1	2	0.45	0.89
16	**	2	4	0.89	1.79
18	**	2	6	0.89	2.68
20	***********	12	18	5.36	8.04
22	******	7	25	3.12	11.16
24	*******************	21	46	9.38	20.54
26	*********************	23	69	10.27	30.80
28	************************	27	96	12.05	42.86
30	*********************************	37	133	16.52	59.38
32	*******************	21	154	9.38	68.75
34	************************	27	181	12.05	80.80
36	************	13	194	5.80	86.61
38	******	7	201	3.12	89.73
40	*********	10	211	4.46	94.20
42	*******	8	219	3.57	97.77
44	***	3	222	1.34	99.11
46		0	222	0.00	99.11
48	*	1	223	0.45	99.55
50	*	1	224	0.45	100.00
52		0	224	0.00	100.00

2 4 6 8 10 12 14 16

Percentage

Figure D18. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 505 (pool 14) nearshore and farshore sites combined, July 1989

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
9		0	0	0.00	0.00
12	*****	1	1	2.38	2.38
15		0	1	0.00	2.38
18		0	1	0.00	2.38
21		0	1	0.00	2.38
24		0	1	0.00	2.38
27		0	1	0.00	2.38
30		0	1	0.00	2.38
33		0	1	0.00	2.38
36	*****	1	2	2.38	4.76
39		0	2	0.00	4.76
42		0	2	0.00	4.76
45		0	2	0.00	4.76
48	*****	1	3	2.38	7.14
51	*****	1	4	2.38	9.52
54	**************	3	7	7.14	16.67
57	**************	3	10	7.14	23.81
60	*******************	4	14	9.52	33.33
63	**********	2	16	4.76	38.10
66	************************	5	21	11.90	50.00
69	**************	3	24	7.14	57.14
72	**************	3	27	7.14	64.29
75	*****	1	28	2.38	66.67
78	*****	1	29	2.38	69.05
81	**********	2	31	4.76	73.81
84	*****	1	32	2.38	76.19
87	**************	3	35	7.14	83.33
90	*******************	4	39	9.52	92.86
93		0	39	0.00	92.86
96		0	39	0.00	92.86
99	*****	1	40	2.38	95.24
102		0	40	0.00	95.24
105	*****	1	41	2.38	97.62
108		0	41	0.00	97.62
111		0	41	0.00	97.62
114		0	41	0.00	97.62
117	*****	1	42	2.38	100.00
120		0	42	0.00	100.00

```
----+---+---+---+---+---+
    2   4   6   8   10  12
```

Percentage

Figure D19. Shell length (mm) frequency histogram of *Amblema plicata* in the upper Mississippi River, RM 504.7 (pool 14), 26 July 1988 (Figure E2 in Miller et al. 1990)*

Shell Length		Freq	Cumulative Freq	Percent	Cumulative Percent
0		0	0	0.00	0.00
2		0	0	0.00	0.00
4		0	0	0.00	0.00
6		0	0	0.00	0.00
8		0	0	0.00	0.00
10		0	0	0.00	0.00
12		0	0	0.00	0.00
14	*******	1	1	3.70	3.70
16		0	1	0.00	3.70
18	***************	2	3	7.41	11.11
20	***************	2	5	7.41	18.52
22	**********************	3	8	11.11	29.63
24		0	8	0.00	29.63
26		0	8	0.00	29.63
28		0	8	0.00	29.63
30	*******	1	9	3.70	33.33
32	*******	1	10	3.70	37.04
34	******************************	4	14	14.81	51.85
36	*************************************	5	19	18.52	70.37
38	**********************	3	22	11.11	81.48
40	***************	2	24	7.41	88.89
42	*******	1	25	3.70	92.59
44	*******	1	26	3.70	96.30
46	*******	1	27	3.70	100.00
48		0	27	0.00	100.00

```
----+---+---+---+---+---+---+---+---+-
    2   4   6   8   10  12  14  16  18
```

Percentage

Figure D20. Shell length (mm) frequency histogram of *Truncilla truncata* in the upper Mississippi River, RM 299.6 (pool 20), 20 July 1988 (Figure E14 in Miller et al. 1990)*

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* See References at the end of the main text.

APPENDIX E

WATER VELOCITY DATA FROM THE UMR, 1989

Table E1

Summary Information from 16 Water Velocity Tests Conducted in the UMR, July and September, 1989

(Note: L - Left descending Bank, R - Right Descending Bank; all Distances are in Feet)

Test	Date	Start Time	Total Seconds	Nearshore Dist.	Nearshore Depth	Farshore Dist.	Farshore Depth	Vessel Dist.	Experimental Conditions	Vessel Direction	Time When Vessel Passed Sensors Bow	Time When Vessel Passed Sensors Stern	Sec From Start	
									UMR Mile 505.5, Pool 14, July 1989					
1	12 July	163528	295	180 L	10	400 L	17	N/A	Ambient	N/A	N/A	N/A	N/A	
2	12 July	165110	84	180 L	10	400 L	17	180 L	21-ft skiff, 6000 rpm, next to inshore buoy	Down	165140	N/A	30	
3	12 July	165731	102	180 L	10	400 L	17	180 L	Two 21-ft skiffs, 6000 rpm, one on each side of buoy	Down	165811	N/A	40	
4	13 July	92000	531	180 L	10	400 L	17	560 L	Tug and barges	Down	92300	N/A	181	
5	13 July	94121	116	180 L	10	400 L	17	600 L	Workboat and two barges	Up	94200	N/A	40	
6	13 July	111942	376	180 L	10	400 L	17	700 L	Tug and 15 barges	Up	112220	N/A	159	
7	13 July	151000	355	180 L	10	400 L	17	750 L	Tug and 15 barges	Up	150305	N/A	120	
8	13 July	162910	695	180 L	10	400 L	17	600 L	Tug and 15 barges	Down	163200	N/A	171	
9	13 July	163410	651	180 L	10	400 L	17	1000 L	Tug and barges	Down	163700	N/A	471	
10	15 July	132141	644	400 L	17	500 L	20	750 L	Workboat and two barges	Down	132400	N/A	140	
									UMR Mile 635, Pool 10, September 1989					
12	18 Sept	163245	663	125 L	10	260 L	12	375 L	Tug and eight barges	Down	163548	163700	184	256
13a	19 Sept	95527	1520	125 L	10	260 L	12	775 L	Work boat and two barges	Up	95828	95856	182	209
13b	19 Sept	95527	1520	125 L	10	260 L	12	450 L	Tug with 12 full, one empty barge	Down	100220	100416	414	530
14	21 Sept	165310	1334	100 R	10	200 R	12	325 R	Tug with 13 loaded barges	Down	165904	170124	355	495
15	19 Sept	91641	241	125 L	10	260 L	12	N/A	Ambient	N/A	N/A	N/A	N/A	N/A
16	21 Sept	132914	622	100 R	10	200 R	12	N/A	Ambient	N/A	N/A	N/A	N/A	N/A

Note: Test 11, which consisted of velocity measurements during ambient conditions, was not plotted.

Table E2

Summary Statistics for a 200-Sec Increment of Water Velocity Data Collected During Passage of Commercial Navigation Vessels in the UMR, 1989*

Test 1

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.189	0.454	0.070	0.632
SD	0.063	0.074	0.050	0.048
Min	-0.341	0.301	-0.077	0.498
Max	-0.032	0.625	0.184	0.747
Range	0.309	0.324	0.261	0.249

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.495	207.498	0.638	209.930
SD	0.078	6.799	0.047	4.571
Min	0.313	189.600	0.508	200.000
Max	0.652	226.200	0.748	224.000
Range	0.339	36.600	0.240	24.000

Test 3

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.186	0.471	0.038	0.609
SD	0.059	0.068	0.052	0.069
Min	-0.367	0.297	-0.097	0.488
Max	-0.057	0.611	0.157	0.802
Range	0.310	0.314	0.254	0.314

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.509	206.559	0.612	211.588
SD	0.069	6.575	0.070	4.760
Min	0.329	191.000	0.491	202.000
Max	0.644	228.400	0.802	224.000
Range	0.315	37.400	0.311	22.000

(Continued)

* With the exception of Tests 1, 15, and 16 (which were for ambient conditions-no vessel passed), statistics were performed for 50 sec prior to vessel passage and 150 sec following vessel passage. See Figures E1-E17 and Table E1 for more details.

(Sheet 1 of 8)

Table E2 (Continued)

Test 4

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.096	0.292	-0.013	0.423
SD	0.079	0.174	0.116	0.173
Min	-0.242	-0.043	-0.271	0.055
Max	0.079	0.501	0.180	0.638
Range	0.321	0.544	0.451	0.583

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.322	192.814	0.446	209.555
SD	0.165	46.820	0.154	21.677
Min	0.004	52.000	0.139	182.000
Max	0.530	325.000	0.643	268.000
Range	0.526	273.000	0.504	86.000

Test 5

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.110	0.378	0.058	0.489
SD	0.043	0.045	0.038	0.067
Min	-0.224	0.279	-0.052	0.333
Max	-0.013	0.488	0.14	0.635
Range	0.211	0.209	0.192	0.302

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.395	206.142	0.493	197.750
SD	0.047	5.984	0.069	3.837
Min	0.287	192.000	0.333	187.000
Max	0.515	221.800	0.643	211.000
Range	0.228	29.800	0.310	24.000

(Continued)

Table E2 (Continued)

Test 6

	Nearshore		Farshore	
	Perpendicular	Parallel	Perpendicular	Parallel
Mean	-0.196	0.544	0.058	0.682
SD	0.090	0.173	0.083	0.135
Min	-0.391	0.167	-0.147	0.401
Max	0.038	0.847	0.231	0.899
Range	0.429	0.680	0.378	0.498

	Nearshore		Farshore	
	Combined Velocity	Flow Direction	Combined Velocity	Flow Direction
Mean	0.582	208.383	0.689	202.825
SD	0.183	7.399	0.140	6.110
Min	0.170	132.100	0.400	191.000
Max	0.863	229.100	0.921	223.000
Range	0.693	47.000	0.520	32.000

Test 7

	Nearshore		Farshore	
	Perpendicular	Parallel	Perpendicular	Parallel
Mean	-0.148	0.447	-0.001	0.491
SD	0.051	0.069	0.039	0.050
Min	-0.312	0.272	-0.097	0.329
Max	-0.038	0.611	0.152	0.661
Range	0.274	0.339	0.249	0.332

	Nearshore		Farshore	
	Combined Velocity	Flow Direction	Combined Velocity	Flow Direction
Mean	0.473	209.162	0.493	214.765
SD	0.073	5.381	0.049	5.015
Min	0.290	196.300	0.358	190.000
Max	0.646	224.400	0.661	228.000
Range	0.356	28.100	0.303	38.000

(Continued)

(Sheet 3 of 8)

Table E2 (Continued)

Test 8

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.138	0.369	-0.042	0.467
SD	0.059	0.100	0.050	0 088
Min	-0.274	0.159	-0.167	0.272
Max	0.017	0.558	0.072	0.628
Range	0.291	0.399	0.239	0.356

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.397	211.104	0.472	219.430
SD	0.108	7.079	0.084	7.592
Min	0.159	185.800	0.289	205.000
Max	0.608	227.800	0.628	237.000
Range	0.449	42.000	0.339	32.000

Test 9

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.116	0.356	0.007	0.506
SD	0.044	0.045	0.037	0.065
Min	-0.255	0.240	-0.104	0.341
Max	-0.020	0.488	0.099	0.658
Range	0.235	0.248	0.203	0.317

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.377	208.920	0.507	211.395
SD	0.049	6.123	0.065	4.147
Min	0.268	194.200	0.341	201.000
Max	0.507	222.600	0.658	224.000
Range	0.239	28.400	0.317	23.000

(Continued)

(Sheet 4 of 8)

Table E2 (Continued)

Test 10

	Nearshore		Farshore	
	Perpendicular	Parallel	Perpendicular	Parallel
Mean	-0.285	0.188	-0.433	0.064
SD	0.187	0.244	0.376	0.490
Min	-0.548	-0.374	-1.317	-0.800
Max	0.070	0.428	0.488	1.454
Range	0.618	0.802	1.805	2.254

	Nearshore		Farshore	
	Combined Velocity	Flow Direction	Combined Velocity	Flow Direction
Mean	0.424	206.114	0.670	273.720
SD	0.177	89.510	0.356	79.948
Min	0.046	0.600	0.089	20.000
Max	0.669	357.900	1.689	370.000
Range	0.623	357.300	1.600	350.000

Test 12

	Nearshore		Farshore	
	Perpendicular	Parallel	Perpendicular	Parallel
Mean	0.072	-0.238	-0.301	-0.048
SD	0.218	0.776	0.705	0.652
Min	-0.252	-1.791	-1.671	-1.236
Max	0.505	0.598	0.528	0.941
Range	0.757	2.389	2.199	2.177

	Nearshore		Farshore	
	Combined Velocity	Flow Direction	Combined Velocity	Flow Direction
Mean	0.675	138.178	0.854	228.600
SD	0.506	94.297	0.537	88.610
Min	0.023	8.700	0.170	4.000
Max	1.846	365.400	1.963	362.000
Range	1.823	356.700	1.793	358.000

(Continued)

Table E2 (Continued)

Test 13-First Event

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	0.005	0.369	0.017	0.576
SD	0.030	0.052	0.118	0.439
Min	-0.080	0.251	-0.391	-1.096
Max	0.094	0.498	0.393	2.313
Range	0.174	0.247	0.784	3.409

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.370	187.007	0.635	176.120
SD	0.051	4.914	0.368	41.317
Min	0.251	168.900	0.032	7.000
Max	0.498	205.400	2.324	322.000
Range	0.247	36.500	2.292	315.000

Test 13-Second Event

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	0.030	-0.094	-0.070	0.076
SD	0.067	0.279	0.225	0.577
Min	-0.105	-0.505	-0.618	-1.334
Max	0.189	0.408	0.488	2.347
Range	0.294	0.913	1.106	3.681

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.277	142.359	0.546	220.210
SD	0.125	117.418	0.311	99.545
Min	0.036	7.000	0.038	7.000
Max	0.513	355.000	2.350	351.000
Range	0.477	348.000	2.312	344.000

(Continued)

(Sheet 6 of 8)

Table E2 (Continued)

Test 14-First 600 Seconds

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	0.022	0.000	-0.024	0.038
SD	0.201	0.075	0.332	0.218
Min	-0.296	-0.202	-0.548	-0.431
Max	0.336	0.154	0.573	0.439
Range	0.632	0.356	1.121	0.870

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.277	142.359	0.546	220.210
SD	0.125	117.418	0.311	99.545
Min	0.036	7.000	0.038	7.000
Max	0.513	355.000	2.350	351.000
Range	0.477	348.000	2.312	344.000

Test 14-Second 600 Seconds

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.046	0.423	-0.086	0.527
SD	0.047	0.071	0.119	0.092
Min	-0.172	0.277	-0.376	0.304
Max	0.065	0.595	0.189	0.772
Range	0.237	0.318	0.565	0.468

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.428	178.481	0.546	180.300
SD	0.070	6.598	0.095	12.579
Min	0.282	159.100	0.322	153.000
Max	0.595	193.800	0.859	213.000
Range	0.313	34.700	0.537	60.000

(Continued)

(Sheet 7 of 8)

Table E2 (Concluded)

Test 15

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.001	0.362	-0.008	0.383
SD	0.036	0.053	0.127	0.527
Min	-0.122	0.192	-0.386	-1.419
Max	0.082	0.526	0.358	2.287
Range	0.204	0.334	0.744	3.706

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.364	187.787	0.546	181.145
SD	0.053	5.866	0.378	64.999
Min	0.195	173.000	0.012	7.000
Max	0.526	205.700	2.295	360.000
Range	0.331	32.700	2.283	353.000

Test 16

	Nearshore Perpendicular	Nearshore Parallel	Farshore Perpendicular	Farshore Parallel
Mean	-0.036	0.311	-0.042	0.356
SD	0.033	0.056	0.100	0.064
Min	-0.134	0.187	-0.327	0.231
Max	0.058	0.424	0.199	0.538
Range	0.192	0.237	0.526	0.307

	Nearshore Combined Velocity	Nearshore Flow Direction	Farshore Combined Velocity	Farshore Flow Direction
Mean	0.315	177.959	0.372	183.895
SD	0.054	6.899	0.065	15.735
Min	0.205	152.300	0.239	150.000
Max	0.425	195.900	0.565	228.000
Range	0.220	43.600	0.326	78.000

(Sheet 8 of 8)

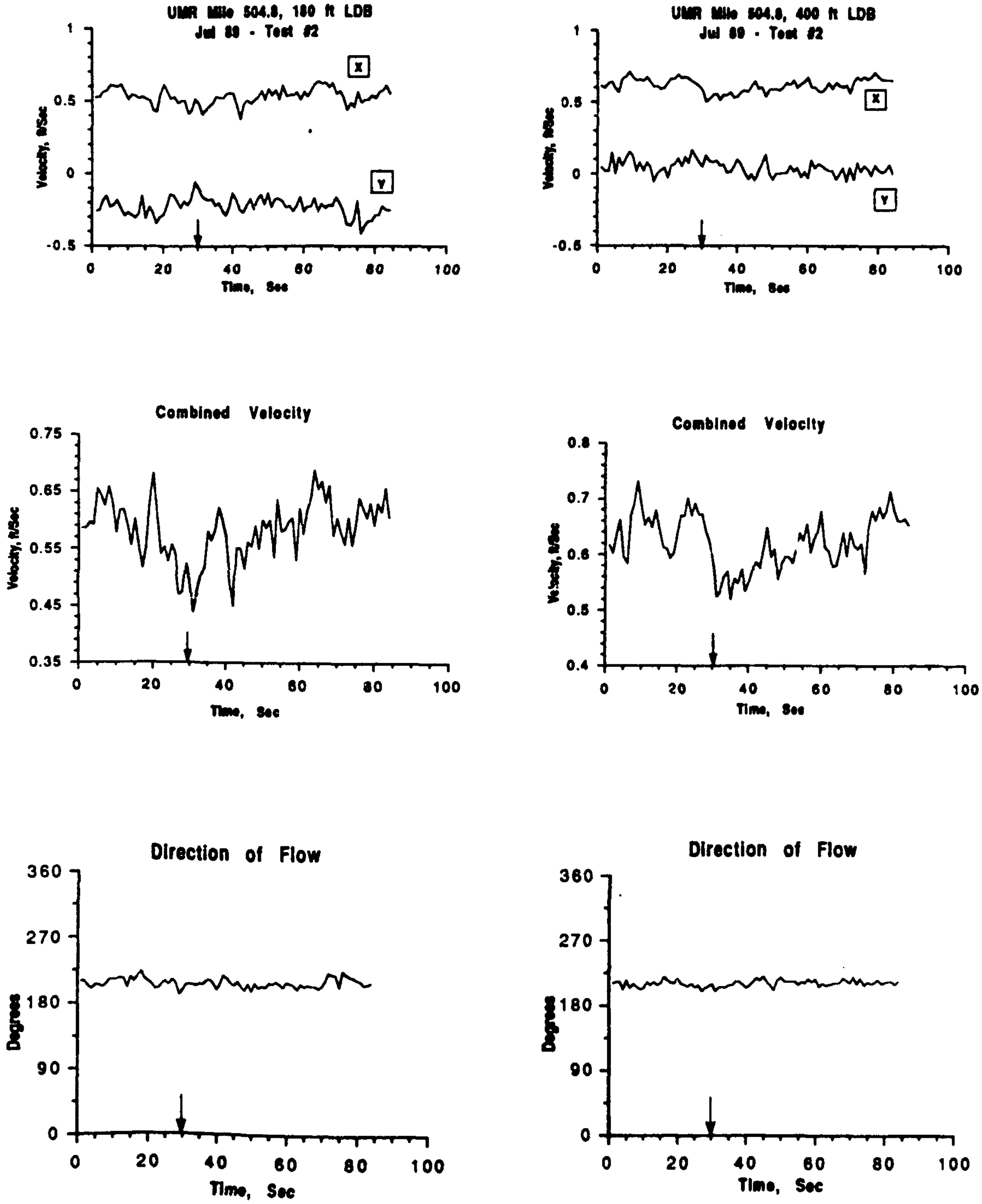

Figure E1. Test 2, RM 504.8, July 1989. The single arrow is the bow of the vessel.

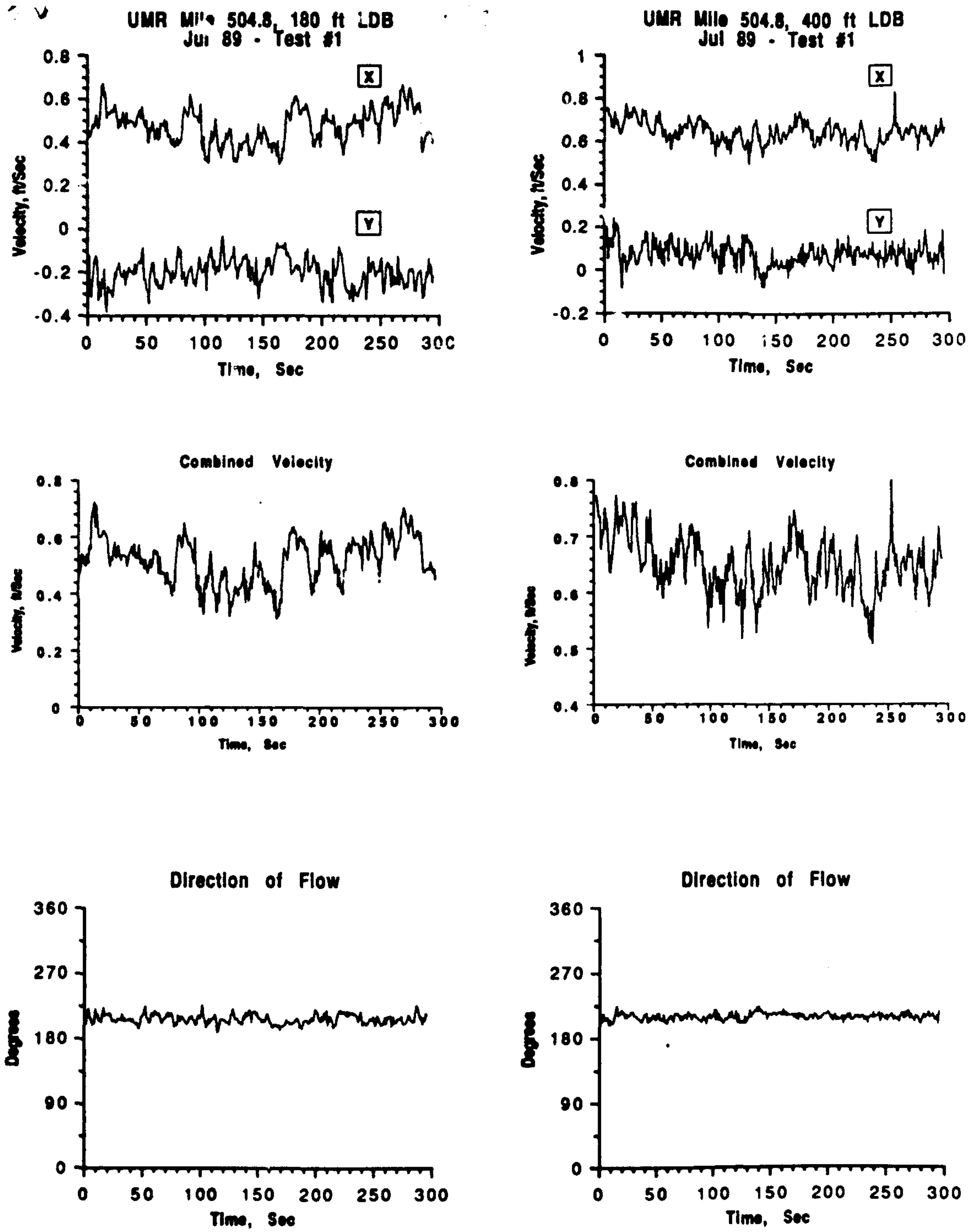

Figure E2. Test 1, RM 504.8, July 1989

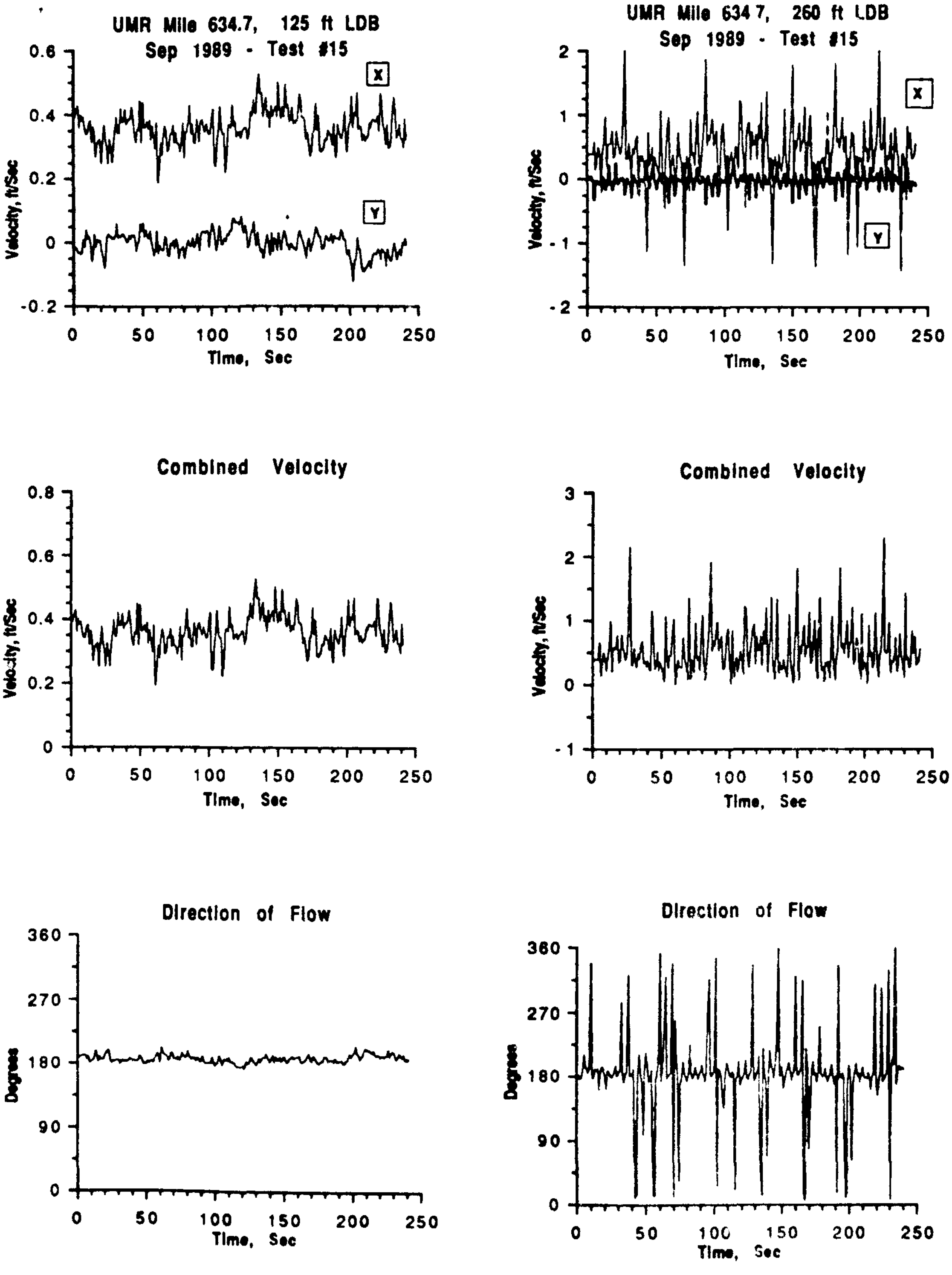

Figure E3. Test 15, RM 634.7, September 1989. Electronic noise is responsible for velocity peaks recorded by the meter at 260 ft LDB

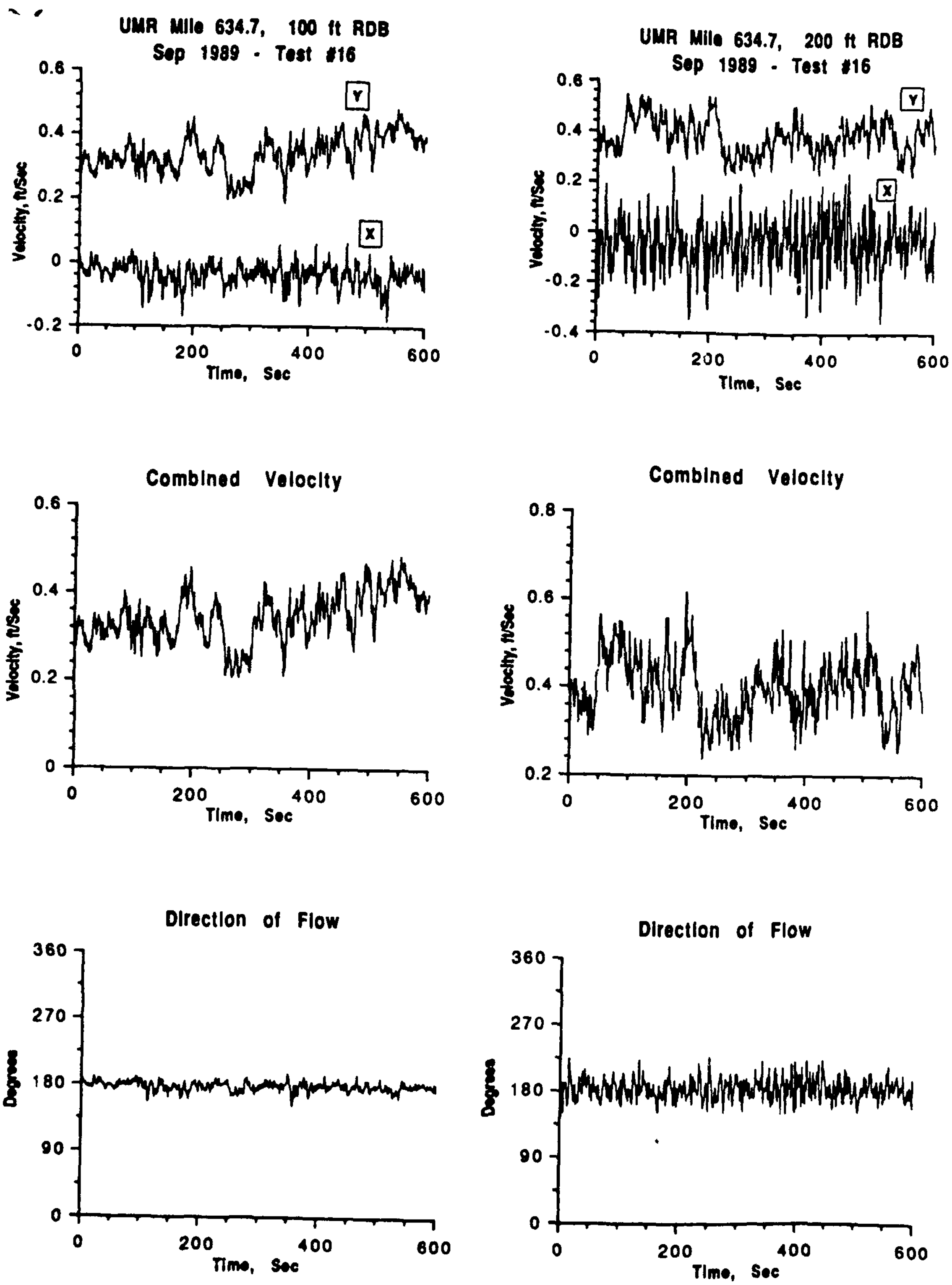

Figure E4. Test 16, RM 634.7, September 1989. Electronic noise is responsible for velocity peaks recorded by the meter at 200 ft RDB

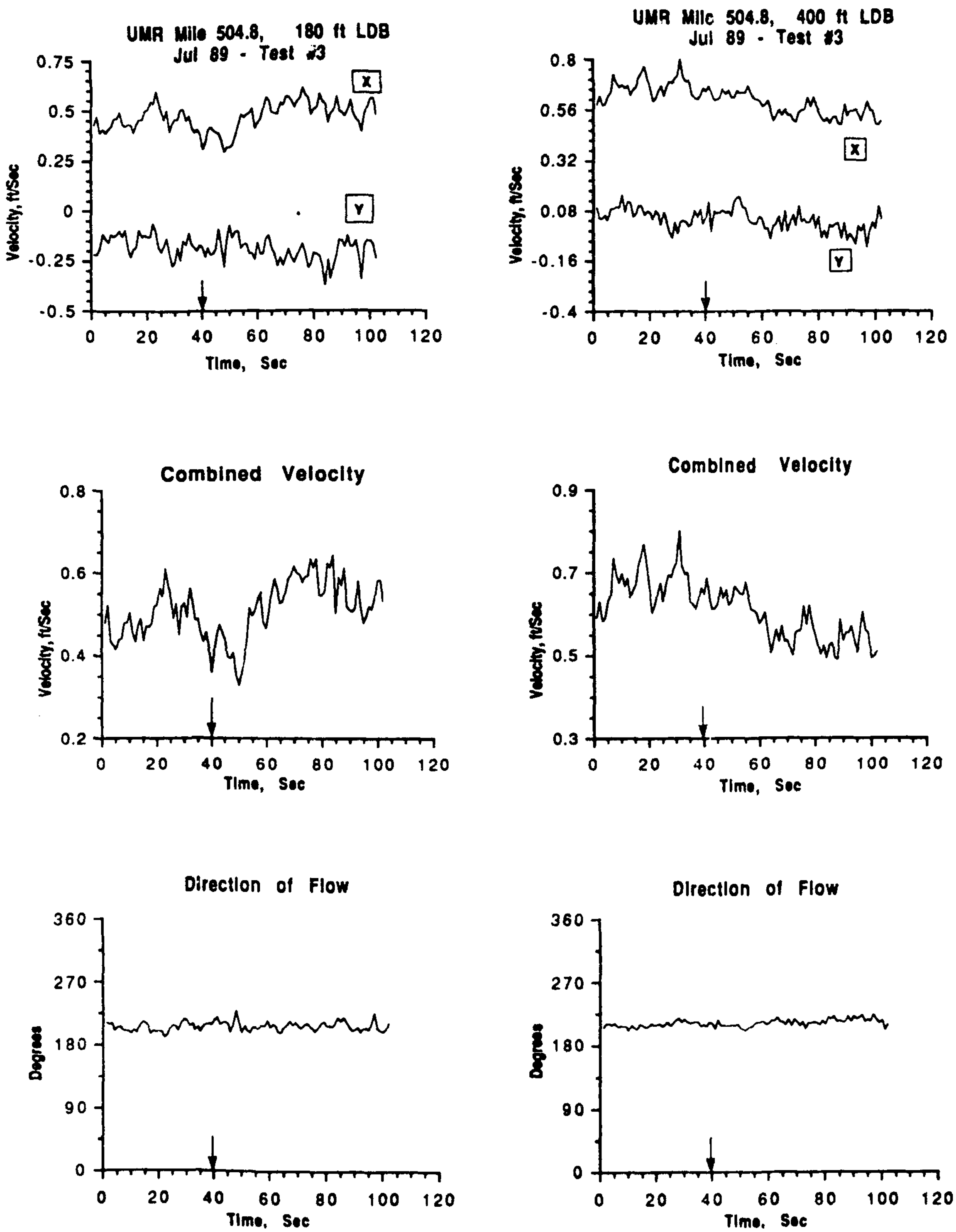

Figure E5. Test 3, RM 504.8, July 1989. The single arrow marks the bow of the vessel

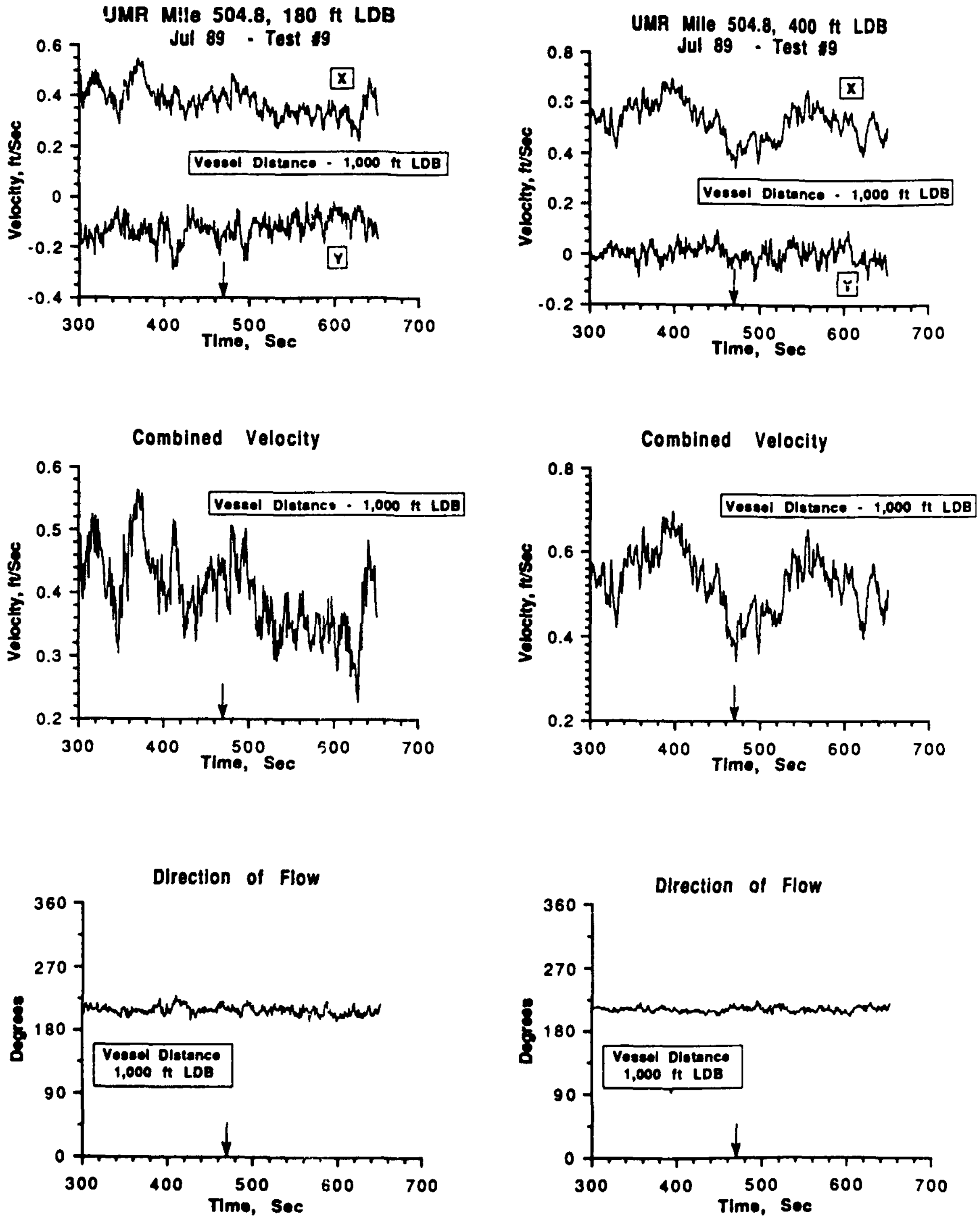

Figure E6. Test 9, RM 504.8, July 1989. The single arrow marks the leading edge of the tow

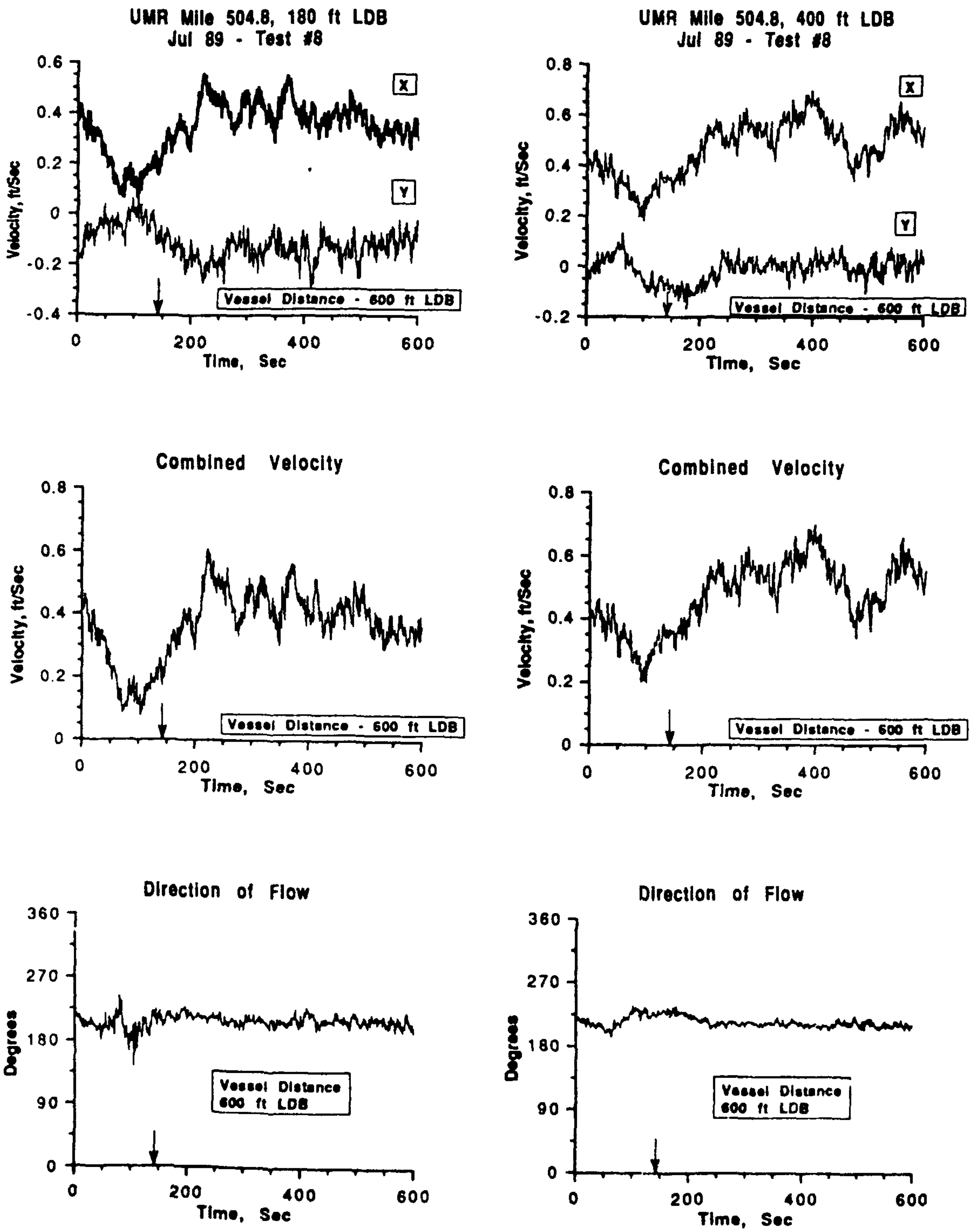

Figure E7. Test 8, RM 504.8, July 1989. The single arrow marks the leading edge of the tow

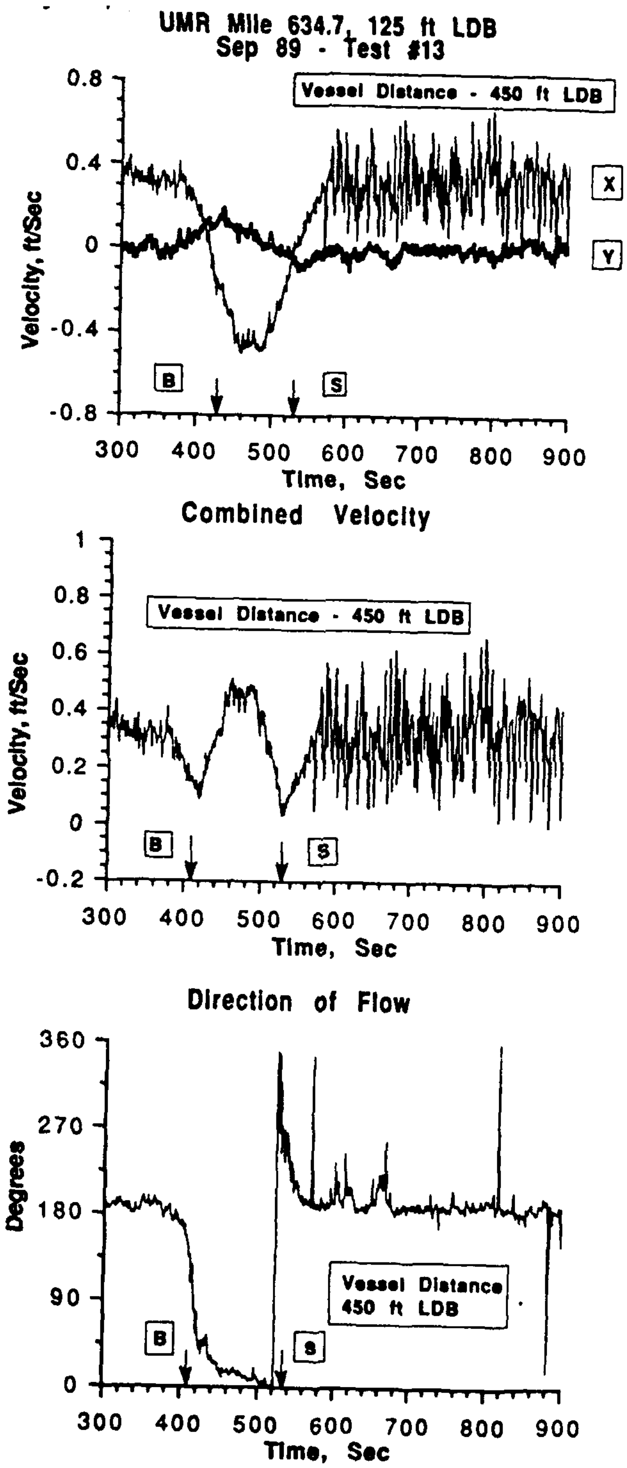

Figure E8. Test 13, RM 634.7, September 1989, vessel distance 450 ft LDB

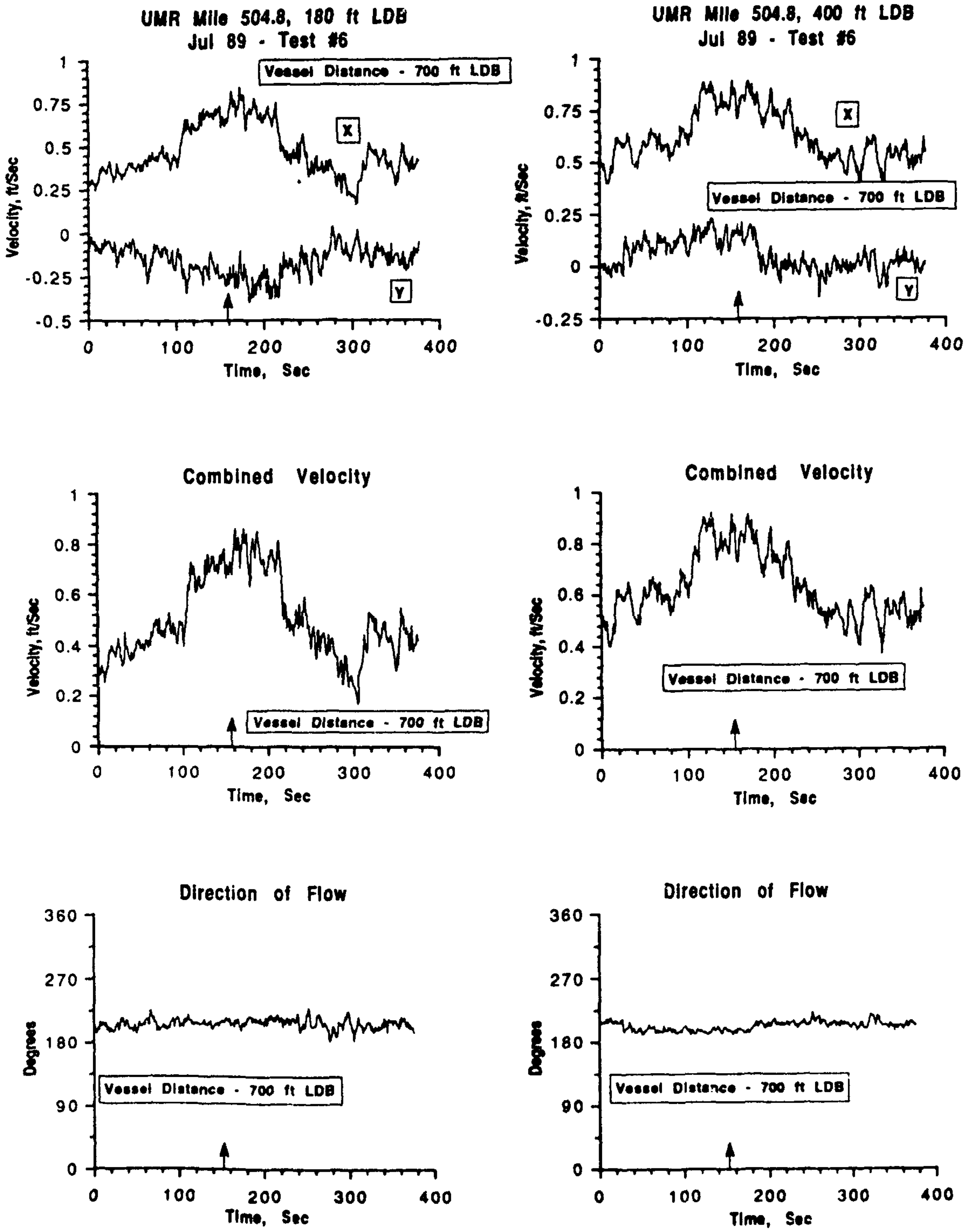

Figure E9. Test 6, RM 504.8, July 1989. The single arrow marks the leading edge of the tow

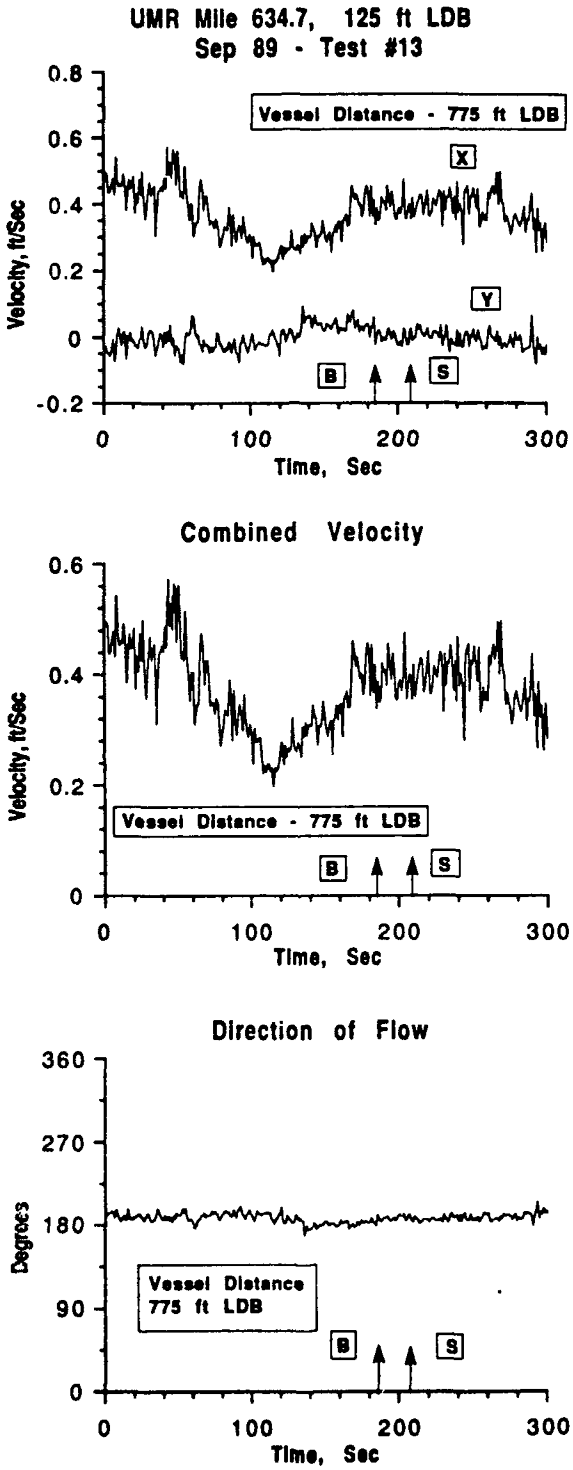

Figure E10. Test 13, RM 634.7, September 1989, vessel distance 775 ft LDB

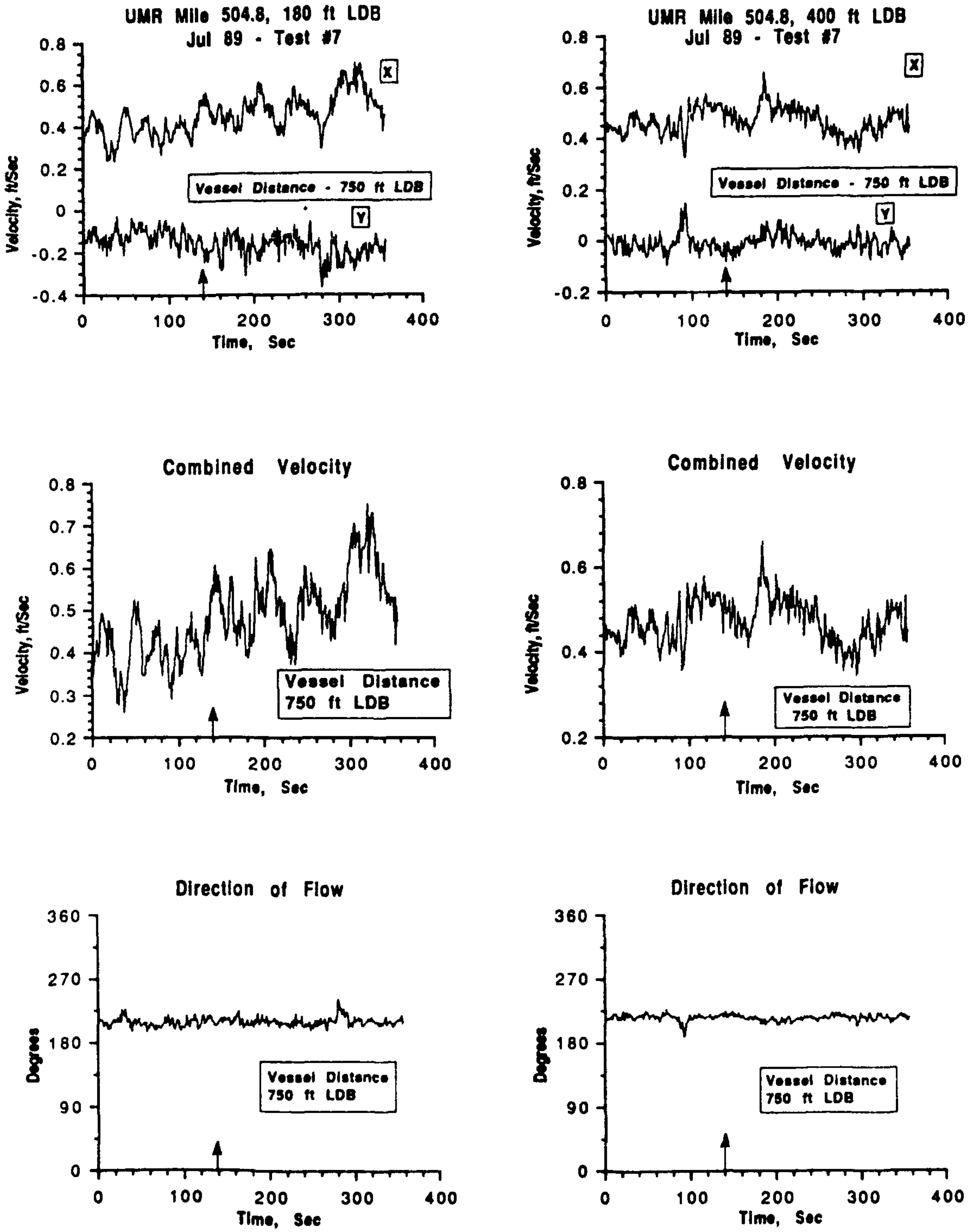

Figure E11. Test 7, RM 504.8, July 1989. The single arrow marks the leading edge of the tow

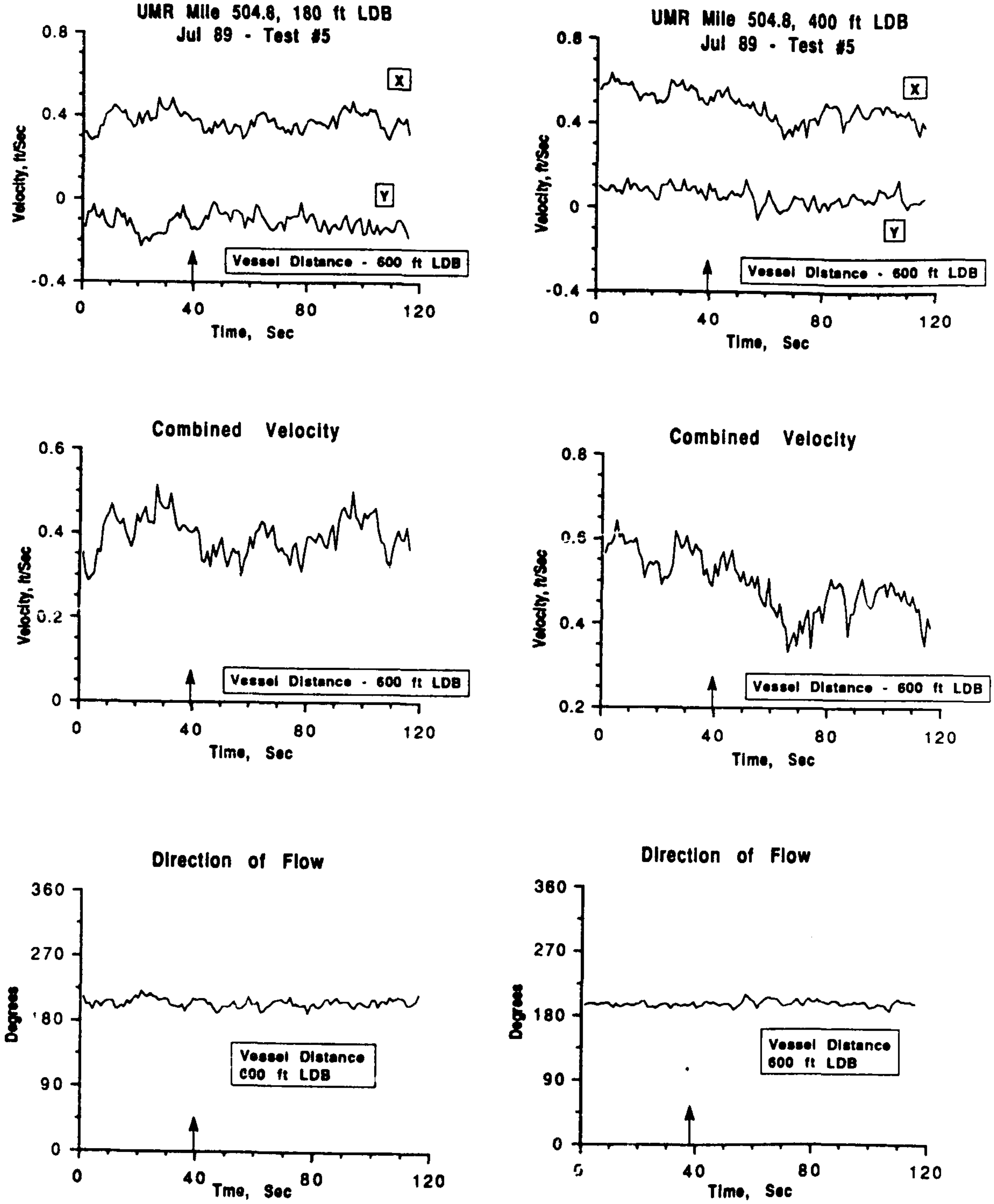

Figure E12. Test 5, RM 504.8, July 1989. The single arrow marks the leading edge of the tow

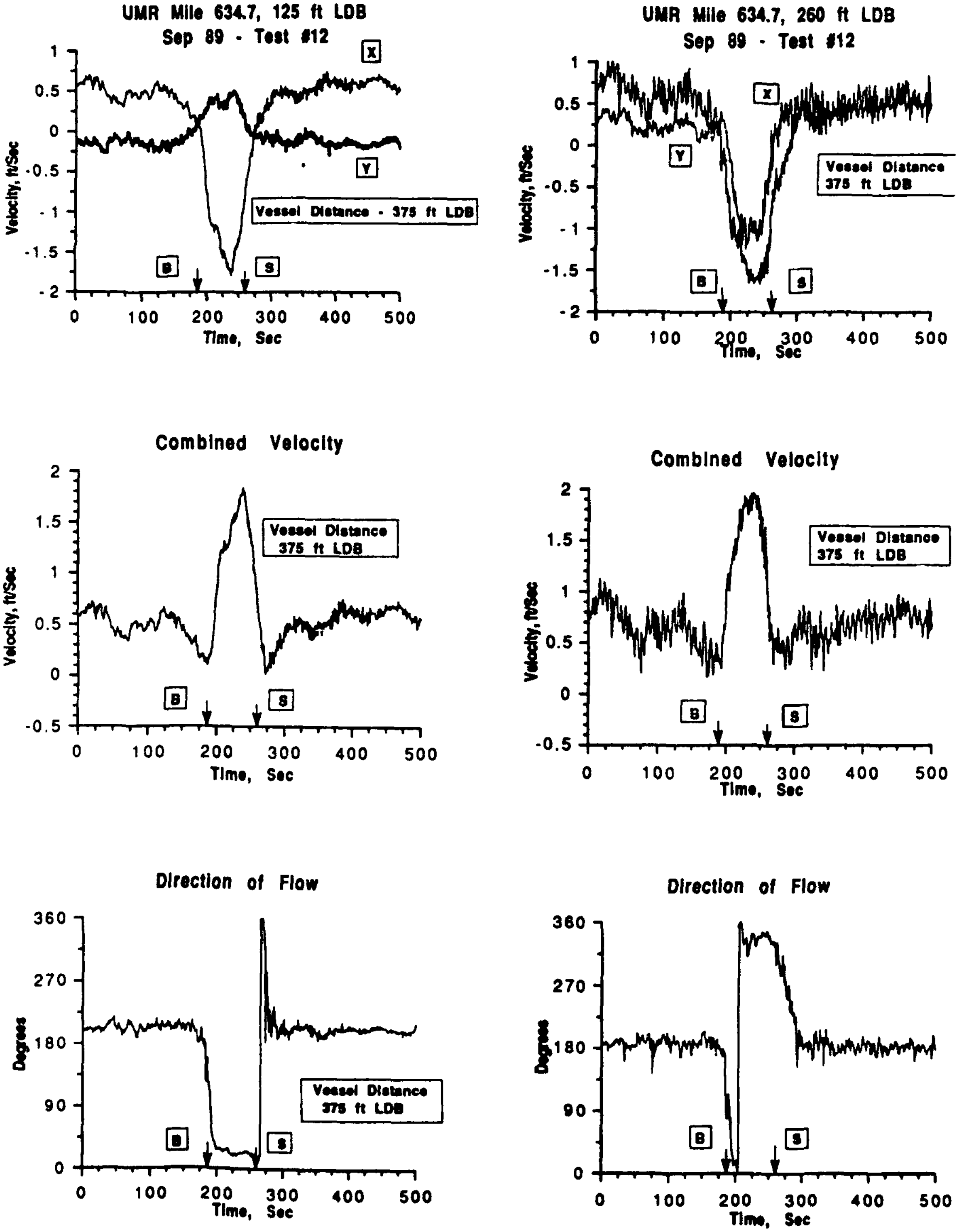

Figure E13. Test 12, RM 634.7, September 1989

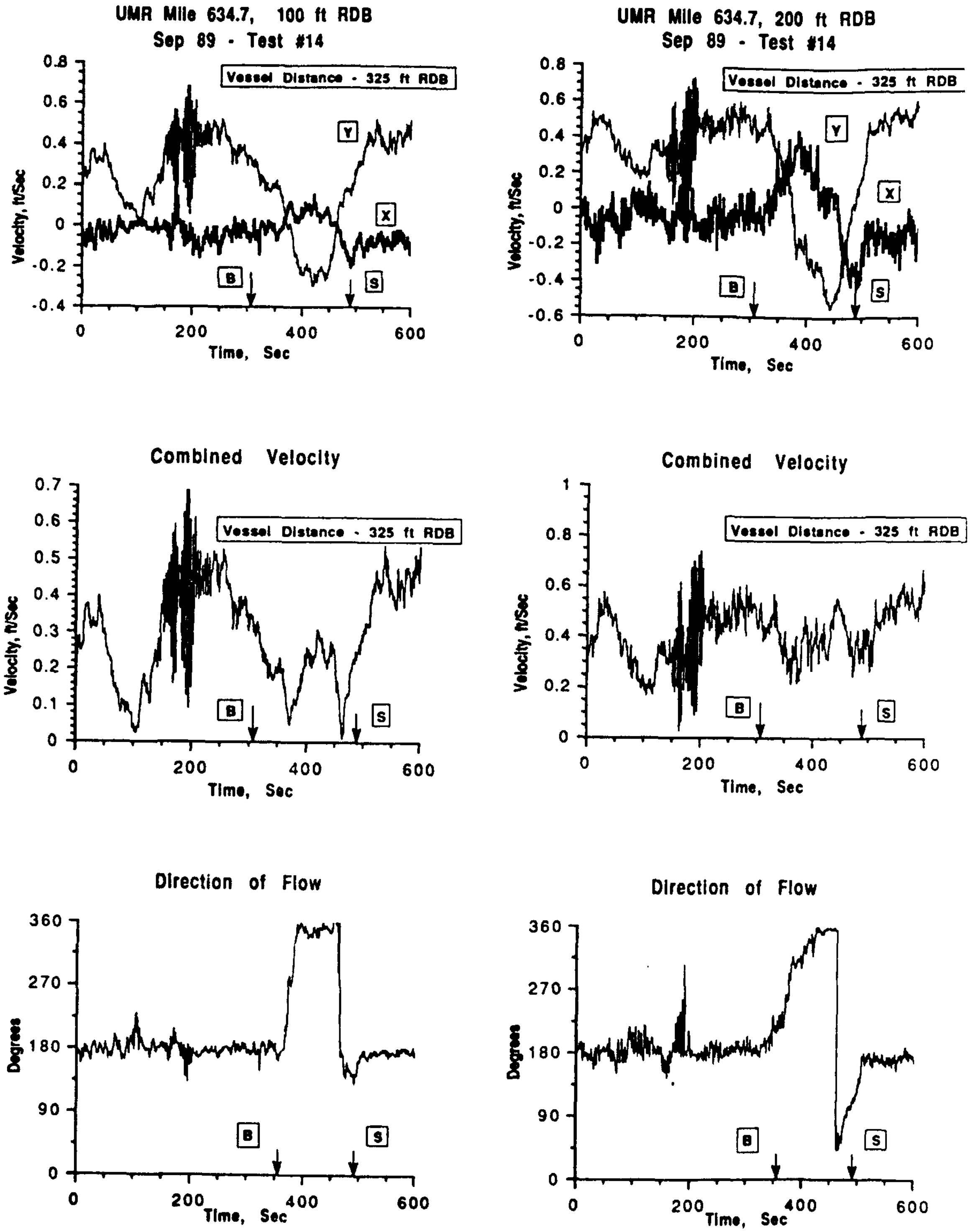

Figure E14. Test 14, first part, RM 634.7, September 1989. The single arrow marks the leading edge of the tow

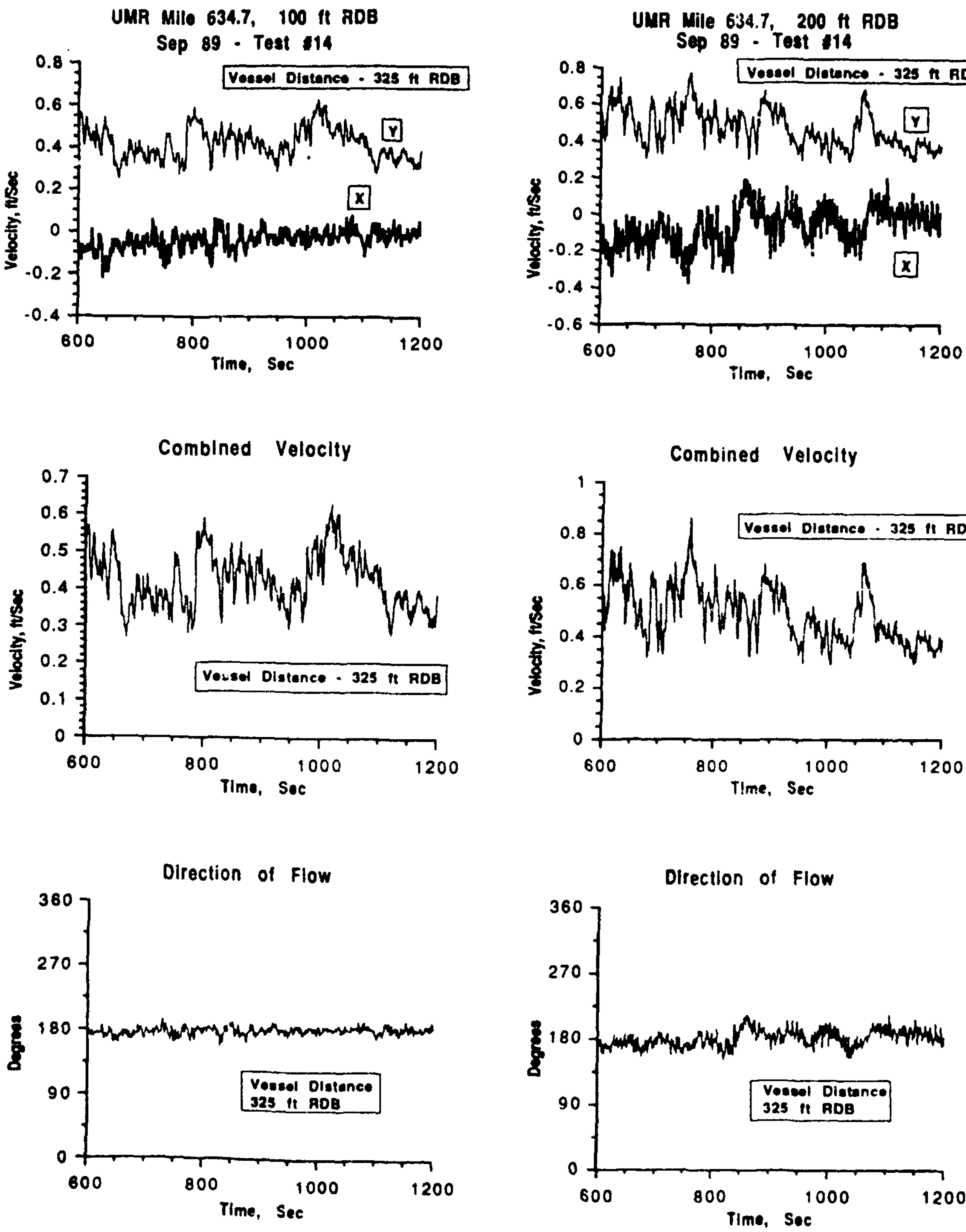

Figure E15. Test 14, second part, RM 634.7, September 1989

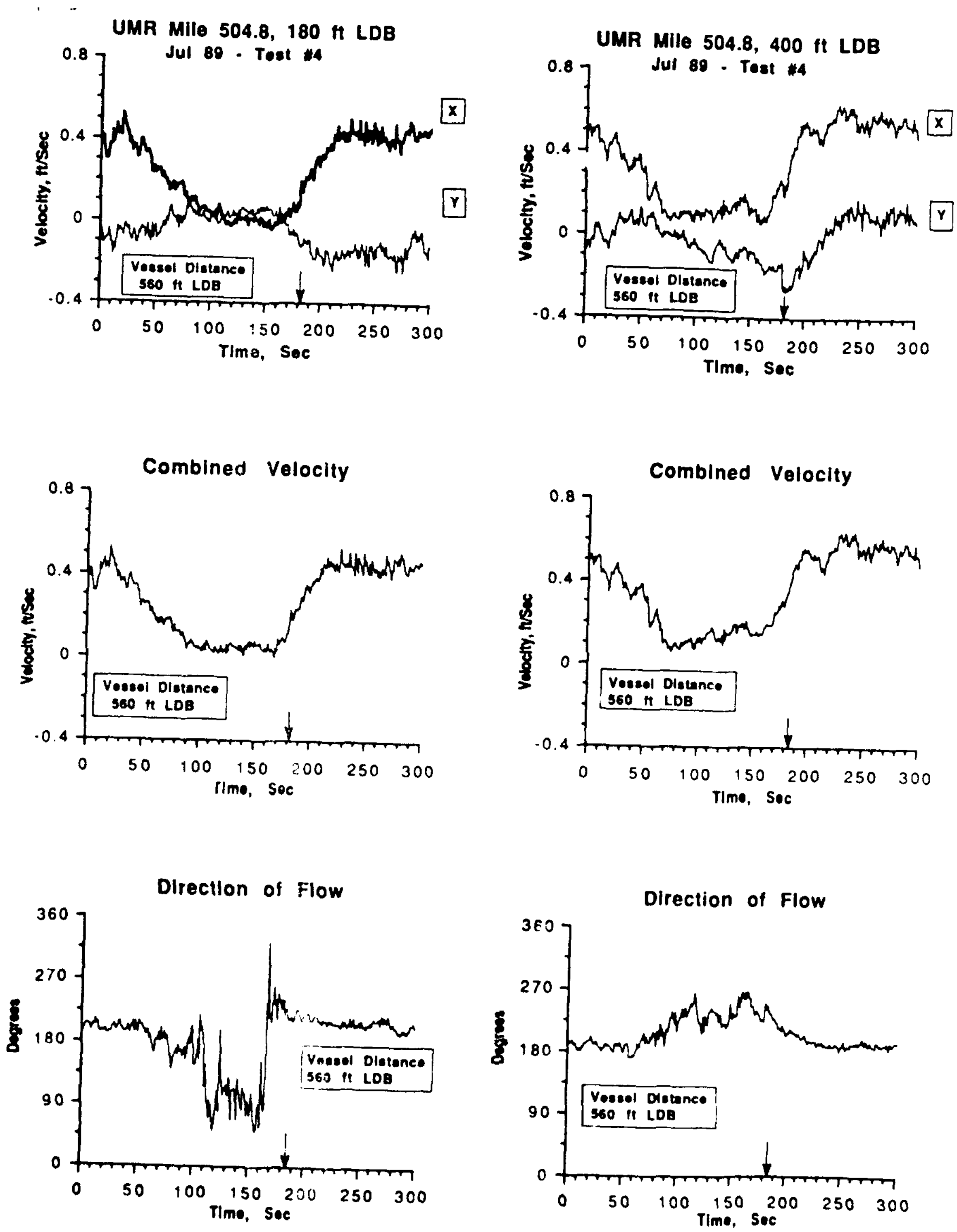

Figure E16. Test 4, RM 504.8, July 1989. The single arrow marks the leading edge of the tow

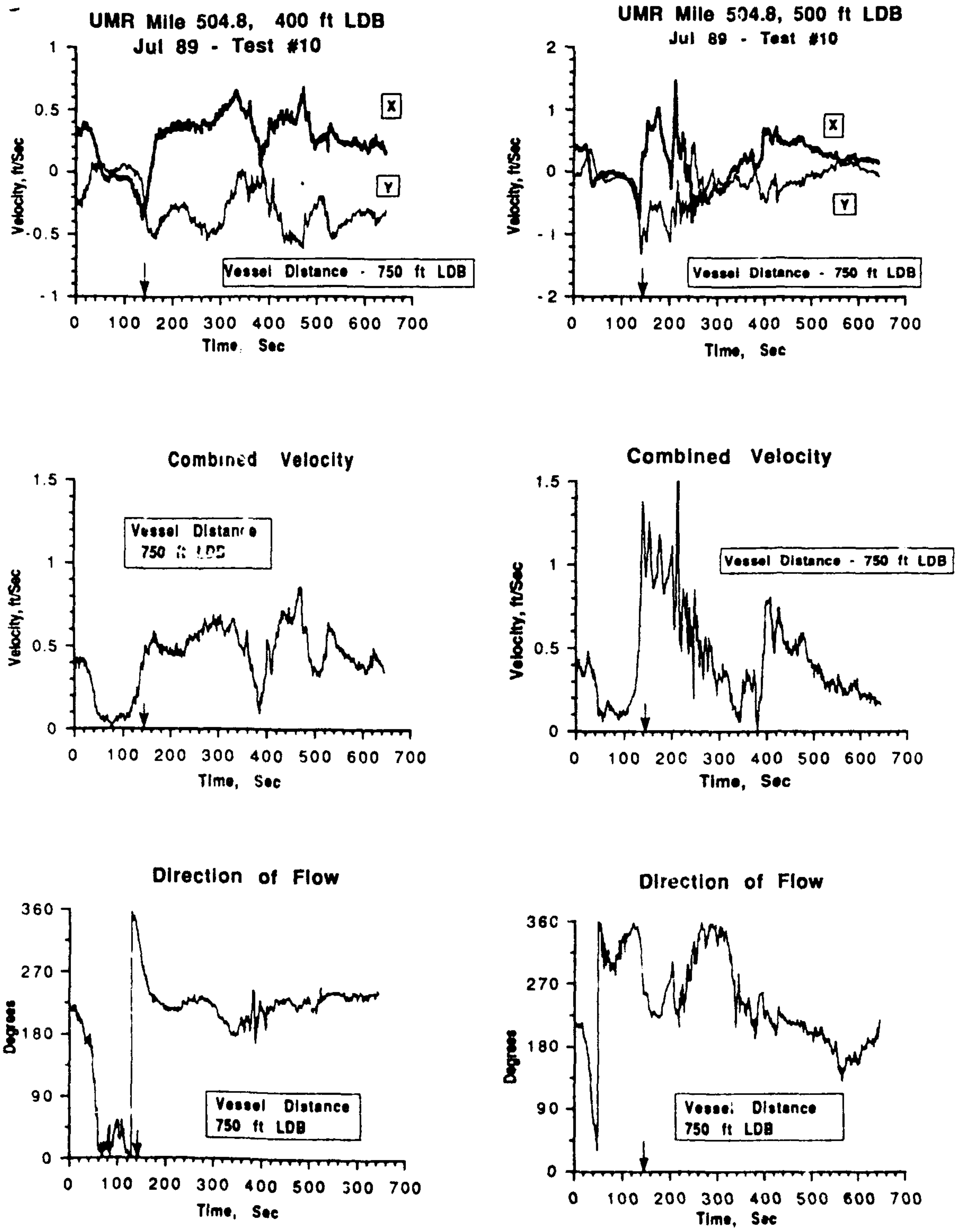

Figure E17. Test 10, RM 504.8, July 1989. The single arrow marks the leading edge of the tow